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JOHN F. KELLY, EDITOR

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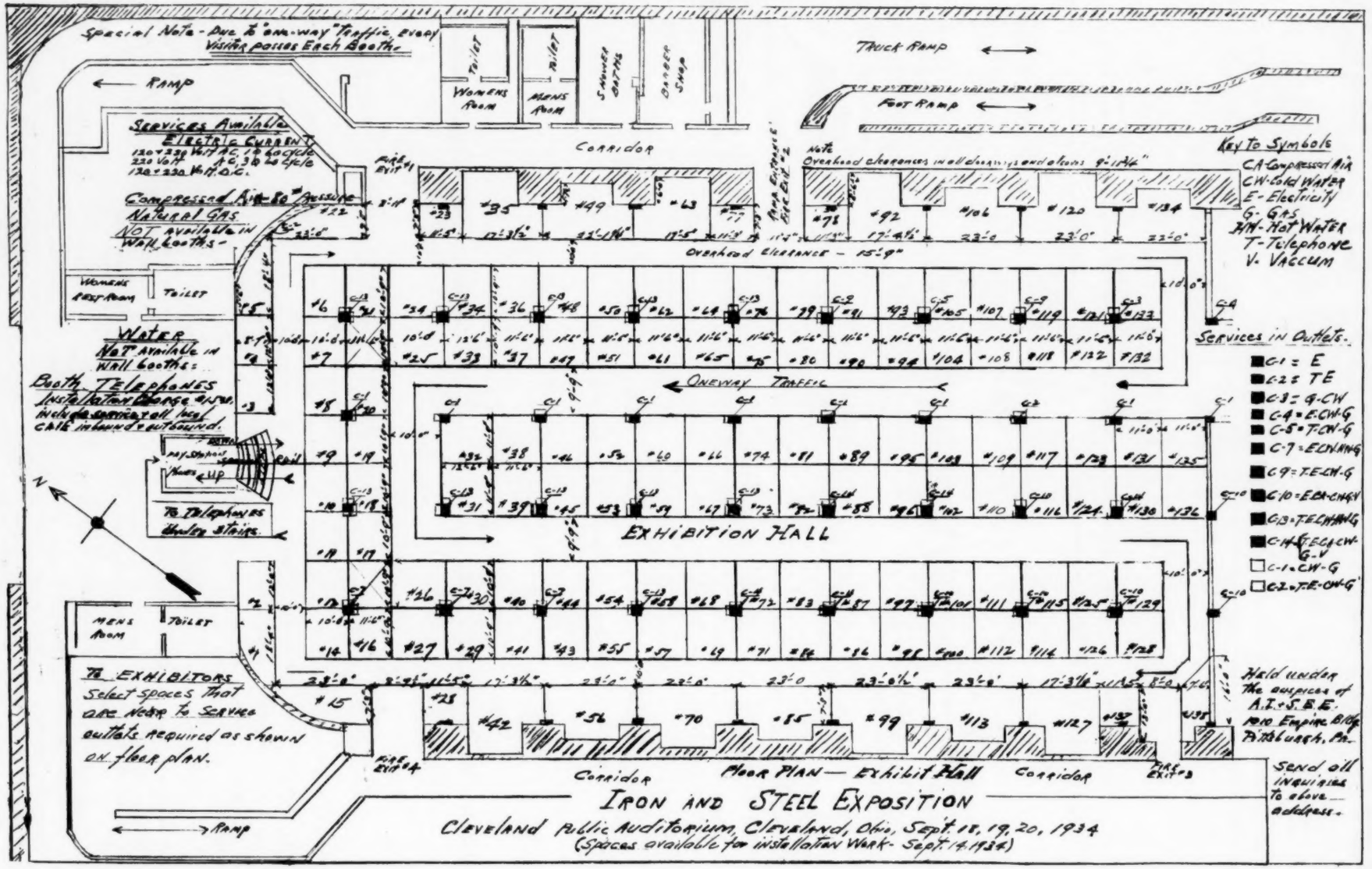
IRON AND STEEL EXPOSITION

CLEVELAND, OHIO, SEPTEMBER 18, 19, 20, 1934



Floor plan of the Iron and Steel Exposition to be held under the auspices of the Electrical, Mechanical, Lubrication, Welding, Combustion and Safety Engineering Divisions of the Association of Iron and Steel Electrical Engineers, Cleveland, Ohio, September 18, 19, 20, 1934. An exposition of the developments in apparatus and equipment to process and produce Iron and Steel.

A. I. & S. E. E. 30th Convention
and
Iron and Steel Exposition
CLEVELAND, OHIO —SEPTEMBER 18, 19, 20, 1934

WHY SHOULD I ATTEND THE A. I. & S. E. E. CONVENTION?

FIRST—To meet the Engineers and Executives of other plants and to discuss informally my routine problems and to exchange opinions and ideas in connection with the design, installation, operation and maintenance of equipment used to process and produce Iron and Steel.

SECOND—To attend the Technical Sessions at which time will be discussed the developments during the last year.

THIRD—The Convention and Iron and Steel Exposition will occupy three days, Tuesday, Wednesday, Thursday, September 18, 19, 20, 1934. Programs are now being arranged for the Technical Sessions which will embrace our Combustion, Lubrication, Mechanical, Welding, Electrical and Safety Divisions. Topics will be presented and discussed which will be of vital and intense interest to every engineering executive and operating official of the Iron and Steel Industry.

FOURTH—One new idea or one new thought expressed in a paper, or at the Iron and Steel Exposition, may enable you to save your plant thousands of dollars. You will contact engineers and operating officials whose problems parallel yours in every respect; their experiences and opinions may aid you in solving your particular problems.

FIFTH—Cleveland is centrally located and little time will be lost in transit.

WHO ATTENDS THE A. I. & S. E. E. CONVENTION?

Electrical, Combustion, Mechanical, Lubrication, Safety Engineers, Master Mechanics, Welding Supervisors, Chief Engineers, Operating Superintendents, Presidents, General Managers.

WHAT IS THE IRON AND STEEL EXPOSITION?

The Iron and Steel Exposition is a show of Steel Mill equipment held in connection with the Annual Convention of the A. I. & S. E. E. and is owned, sponsored and controlled by the Association of Iron and Steel Electrical Engineers; the only engineering society in the industry. The first exhibit took place in 1919 at St. Louis, Mo.

WHY SHOULD AN EQUIPMENT MANUFACTURER BE REPRESENTED IN THE IRON AND STEEL EXPOSITION?

The object of the Iron and Steel Exposition is to acquaint engineers with the status of the art in reference to the various lines of apparatus used in the Industry. Accomplishments by the use of improved devices, new applications, etc., largely form the subject of the papers and discussions of the Annual Convention. The apparatus used in improvement of the quality of product and economy of operation develop the urge to make improvements. Exhibits and Expositions develop this urge into a real desire as concrete suggestions and ideas are presented in the equipment displays. Your equipment will do certain things for the Steel Industry. Show the men who actually spend the gigantic appropriations just what it will do and how it will do it. These are the men who will decide just whose equipment will be used. Are they entirely familiar with your products? Put your equipment in the Iron and Steel Exposition where the engineer can operate it, examine it and thoroughly satisfy himself just how it will meet his needs in the field.

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EDITORIAL

Credit Given Where Due

Agile engineering minds are always stimulated by discussions of scientific subjects which are still in the formative state or have little practical background. More so does this interest grow when there is introduced debatable matters which have been exposed to the all destructive elements of practical usage.

Following this trend of thought there is presented in the editorial pages of this May issue of the Iron and Steel Engineer papers and discussions which embrace those necessary characteristics of highly interesting subject matter; namely, expositions of products and process which have been applied but still retain their controversial nature.

To be able to publish editorial matter of this high caliber is, in a large measure, due to the liberal attitude of the steel industry in permitting its engineers and research men to present to the industry, as a whole, the results of their studies in the laboratories as well as in the field of practical application.

Much credit is also due the engineers of the Industry who have so unselfishly passed on their findings in the field of operation to the rest of the engineering fraternity.

With the helpful attitude of the steel industry, together with the willingness of its engineers to assemble pertinent data concerning the operation of a steel plant, the editorial columns of our official organ, the Iron and Steel Engineer, shall continue to be an almost invaluable aid to the steel mill engineer.

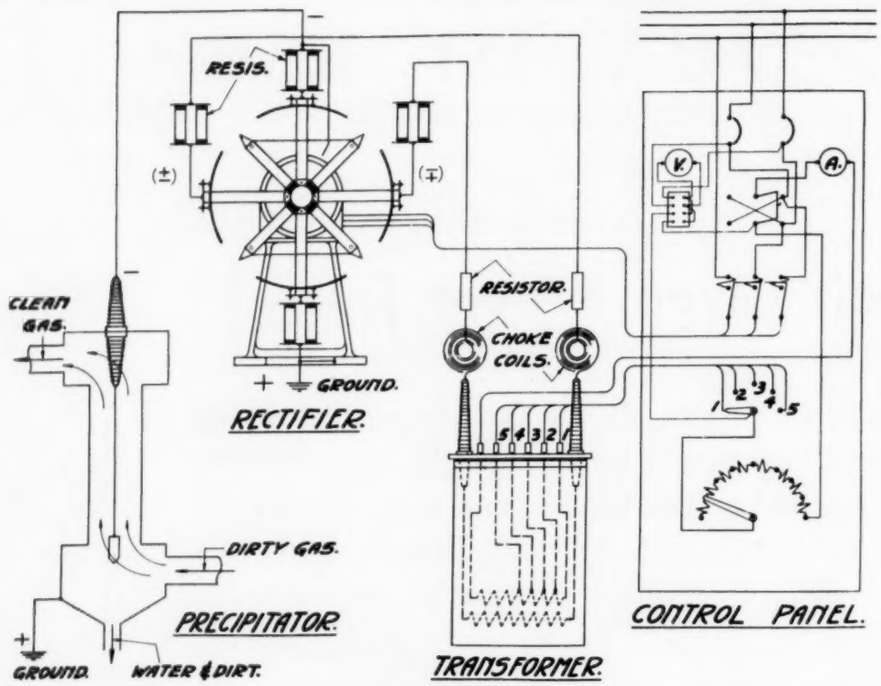


FIG. 1—Schematic diagram of the electrical equipment used on an electric precipitator installation using a mechanical rectifier.

Electrical Precipitators For Cleaning Washed Blast Furnace Gas

By K. E. DINIUS,
Chief Testing Engineer, South Works
Illinois Steel Company, South Chicago, Ill.

Presented before the Chicago District Section of the A. I. & S. E. E., February, 1934.

The fundamental theory of electrical precipitation is by no means a new idea. It was first suggested by Hohlfeld in 1824. However the development was slow and very little of practical value was accomplished until in 1903-4 when Dr. F. G. Cottrell applied the principles to the precipitation of sulphuric acid mist. Since that time the development has been quite rapid and today electrical precipitation is used extensively in the removal or recovery of solids and liquids from air or gases. The cleaning of blast furnace gas is only one of its many applications.

Gas or air under normal conditions is not a conductor of electricity. However if it is passed between two electrodes impressed with a high potential it is put in a state of strain due to the field of electric force surrounding the electrodes. This strain increases with an increase of potential until a point is reached where the gas breaks down and a discharge or momentary current passes from one electrode to the other. This breakdown of the gas is known as ionization. With small electrodes spaced fairly close together the breakdown appears to be instantaneous and the discharge or flow of current appears as a spark. It is not necessary however, to have a complete breakdown of the gas or air as evidenced by the spark discharge. If the electrodes are spaced farther apart the applied potential may be so adjusted as to stress only that portion of the gas immediately surrounding the electrodes to the point of breakdown or ionization. This ionization will appear as a uniform luminous discharge, known as corona, surrounding the electrodes and will extend out to such a distance as the unit stress is sufficient to break down the gas. If one electrode is made very small or filamentary in comparison to the other, the unit stress will be greater around the small electrode for any given applied potential. Consequently by making one electrode very small as in the form of a wire, and the other very large as in the form of a plate, a suitable voltage may be impressed to produce a corona discharge around the small one and leave a comparatively low intensity field around the large one. This is the principle used in the electrical precipitation process.

Thus the process may be said to consist of passing the gas through an electrostatic field of sufficient strength to produce ionization of the gas and form a corona discharge. This condition is obtained by passing the gas between collecting electrodes and ionizing or discharge electrodes which are impressed with a high voltage unidirectional current. In general the collecting electrodes consist of plates or tubes which form the gas passages while the discharge electrodes consist of wires suspended between adjacent plates or axially within the tubes. For the best results unidirectional current is used, with the wires or discharge electrodes connected to the negative side of the high potential source and the plates or tubes connected to the positive side through ground. As the gas passes through this electrostatic field it becomes ionized, producing a corona discharge, due to the high intensity field surounding the small negative electrode. Dust and dirt particles carried by the gas take on a free negative charge and are repelled to the collecting electrodes where a positive low intensity field exists. When these particles reach the positive electrode they give

up their charge and are held to the surface by adhesion. At frequent intervals, depending upon the amount of material precipitated, it must be removed from the collecting plates or tubes. This is accomplished in various ways, such as rapping, scraping or washing down with a cleaning solution. In the cleaning of washed blast furnace gas it has been found that a continuous flow of water over the collecting electrodes, with an occasional flushing with a heavy stream of water, provides the most satisfactory means of removing the precipitated material. Although moisture and conditions of humidity have some affect upon the ionization of a gas and the corona discharge, the continuous flow of water does not materially affect these conditions in the cleaning of washed blast furnace gas. The gas is practically saturated when it enters the precipitator and the addition of the continuous stream of water does not change the existing conditions to any great extent.

K. E. DINIUS

Since the best results are obtained by using a unidirectional current on the electrodes, the most essential requirement of the electrical equipment for any precipitator installation is that it be able to furnish a continuous supply of such current. Because of the impracticability of trying to build D.C. machines for the high voltages required in this process it is standard practice to use alternating current stepped up through transformers, to the desired value and rectified. That is, converted into unidirectional current. Where two or three phase alternating current is available a synchronous induction motor is used to drive a mechanical rectifier which rectifies the secondary current from a special step-up transformer receiving power from the same supply. When only direct current is available a motor generator set is provided to supply alternating current to the transformer. In this case the mechanical rectifier is direct connected to the shaft of the alternator.

Where Alternating Current is available, a control panel is provided with the necessary overload and no-voltage protective devices, meters, regulating and switching equipment, polarity reversing switch and a starting switch for the rectifier motor. The transformer is provided with taps on the low tension side, which are brought out to a tap switch on the control panel. A rheostat is provided in the primary circuit to give closer voltage regulation and minimize the effect of surges fed back from the high voltage circuit. The high tension terminals and rectifier terminals are also provided with special resistance tubes and choke coils to reduce the effect of surges and oscillations resulting from the spark discharges and trouble in the high voltage circuit. The polarity reversing switch is used to reverse the primary terminals of the transformer in case the rectifier motor starts up 180° out of phase, making the discharge of electrodes positive instead of negative. This would be indicated by a spark gap polarity indicator on the rectifier. Fig. 1 illustrates in a schematic manner the essential electrical equipment and circuits used in a typical installation using mechanical rectifiers.

In more modern developments vacuum tube type rectifiers are used in place of mechanical rectifiers. High voltage vacuum tubes capable of passing current in only one direction, are used for this purpose.

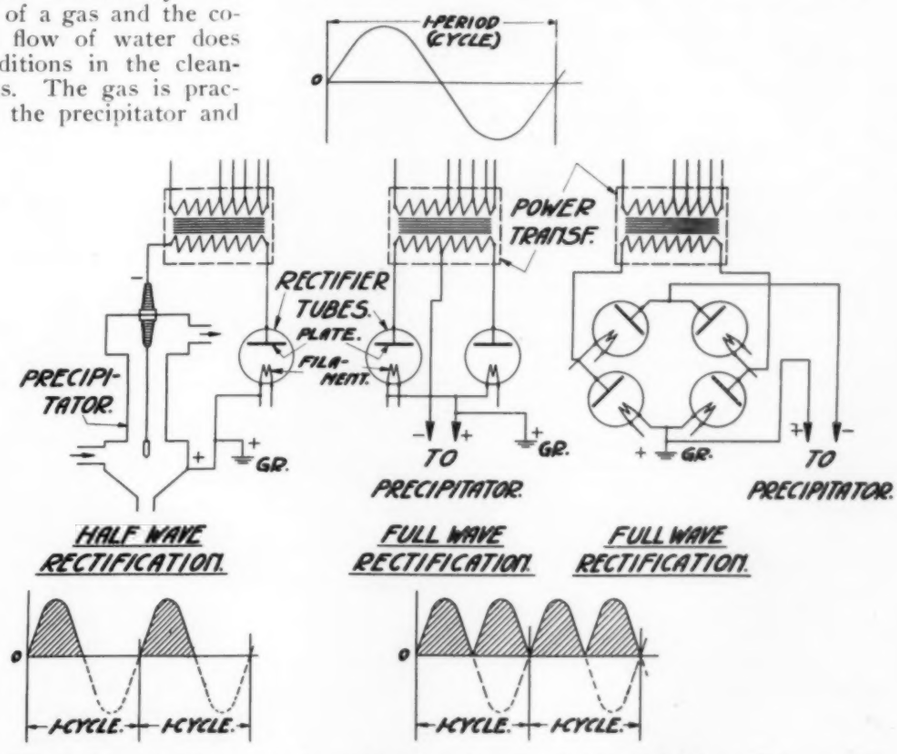


FIG. 2—Schematic diagram of the equipment used on an electric precipitator utilizing rectifier tubes.

They require less space than a mechanical rectifier, are free from rectification surges, supply a regular wave form and constant voltage, provide automatic polarity control and are very quiet in operation. Various rectifier circuits and tube arrangements may be used for half or full wave rectification. Figure 2 represents a few typical examples. Control equipment for vacuum tube type rectifiers has been designed to give full automatic control with short circuit and overload protection, and provide constant current in the electrode circuit. Due to many advantages which are apparent in this method of rectification it is probable that within the near future it will be used entirely in preference to mechanical rectification.

The installation at South Works consists of two 1500 CFM precipitators, each of which is complete with its own transformer, rectifier and control equipment. During normal operation each unit is operated independently, but in cases of emergency both units can be operated from either transformer and rectifier. This is provided for by a special remotely operated disconnect switches in the high tension circuits, which are so arranged that either one or both of the precipitators may be connected to either rectifier. These switches are also arranged so that in the off or disconnected position the high tension lines and electrodes are thoroughly grounded.

The high tension lines from the rectifiers to the precipitators consist of copper tube bus work mounted on high tension insulators. For safety purposes and protection from the weather, the bus and insulators are enclosed with light gauge sheet metal tubing. The terminal insulators, just inside the precipitators, are surrounded with steam coils to prevent them from sweating or collecting moisture from the gas.

The older precipitator has a 7½ KVA transformer and the newer one a 15 KVA. Both are nominally rated 400 volts primary and 50000 to 75000 volts secondary with taps on the primary winding to give increments of 5000 volts on the secondary. Where the supply voltage is in excess of 400 volts or the required secondary voltage is less than 50000 volts, the correct values are obtained by reducing the supply voltage with line resistance. Power is supplied from the plant 440 volt system and is reduced somewhat by the regulating resistance in the primary circuit. At the time of installation it was found by test that approximately 43000 volts on the precipitator gave the best results. This is obtained by using the highest ratio tap and reducing the primary voltage to about 230 volts with the regulating rheostat. Although this is not as efficient as using a lower voltage tap and less resistance drop, it is done to obtain the choking or damping effect of the primary resistance which gives more uniform current characteristics.

Under normal operating conditions the total precipitator load, including resistance losses and power to drive the rectifier, will average less than 10 KW per machine. Where precipitators alone are used and a slight drop in gas pressure through them is not objectionable, this may be considered the total power requirements for gas cleaning by this process. However, in installations such as this at South Works, where they are operated in parallel with Theisen type gas washers and disintegrators which boost the pressure of the gas, it is necessary to install booster fans to force or pull the gas through. On these installations fans have been installed in the clean gas mains of each machine, with a 75 HP adjustable speed motor on the one and a 40 HP adjustable speed motor on the other. A larger fan requiring 75 HP was installed on the second machine because it was found by test that the machines would deliver much more than normal rating with satisfactory cleaning. The power requirements of these fans is determined by the amount of gas being sent through, and the fan speed necessary to deliver this quantity of gas at the proper pressure. Even if it is necessary to operate the booster fan motors at full capacity, the total power required for this method of cleaning washed blast furnace gas is considerably less than that required by Theisen type gas washers or disintegrators. The gas washers rated at 15000 CFM, and used at this same location, are equipped with 200 HP motors and the disintegrators rated at 40000 CFM have 400 HP motors. Thus the total installed capacity for the precipitators, which are rated the same as the gas washers, is approximately 53 HP on one and 88 on the other as compared to 200 HP for the gas washer.

Very little trouble has been experienced with the electrical equipment on either precipitator. On several occasions during snow storms and very bad weather, insulators on the high tension bus have broken down due to rain or snow blowing into the protecting pipe. However it is proposed to replace the high tension bus with a special high voltage cable which has been designed for this service and may be run underground, in conduit or suspended in open wiring. In one case of trouble it was found that one of the negative electrode wires broke and grounded. In the course of operation it has been found desirable to flush the precipitator once during each eight hour turn to prevent accumulations of dirt which is not carried away by the constant flow of water. Among other items which must be given attention occasionally are the terminal insulators inside the precipitator shell. Although they are not in the direct path of the gas they are exposed to it at all times and tend to collect a certain amount of dust and dirt which forms a leakage path over the surface. This is indicated on the voltmeter and ammeter on the control panel which show a gradual increase in current and dropping off of the voltage. In order to avoid delays due to severe leakage or insulator failures they are thoroughly cleaned at regular intervals. In general, it may be said that with a reasonable amount of attention and normal replacement of worn parts, the precipitators are practically trouble free.

Electrical Precipitation As Applied To Secondary Cleaning of Blast Furnace Gas

G. T. HOLLETT

By G. T. HOLLETT,
Steam Engineer, South Works,
Illinois Steel Company, South Chicago, Ill.

Presented before the Chicago District Section of the A. I. & S. E. E., February, 1934.

You have just heard Mr. Dinius deal with the electrical end of the Cottrell type electric precipitator. It is my part to deal with the mechanical end. I shall attempt to show the application, development, and results obtained at South Works of the Illinois Steel Company with the Cottrell electric precipitators used in connection with gas driven electric generators at No. 1 Power Station.

In the modern steel plant there are a number of important by-products each of which must be used to the best advantage either inside the plant to secure economical operation, or outside to secure maximum return. One of the major by-products used inside the plant is the gas produced by the blast furnaces. A blast furnace producing 1000 tons of pig iron per twenty-four (24) hours will produce gas at the rate of approximately 93,000 cubic feet per minute. On account of the low heat content of this gas it is uneconomical to store in gas holders, so it must be used as produced. The uses to which it is put depend largely upon the degree of cleanliness of the gas.

Gas leaving the blast furnace contains a large amount of heavy particles of iron-oxide, coke, etc., most of which is removed by the conventional type of dust catcher. Where the gas is to be used in blast furnace stoves and for metallurgical purposes it is essential that a large percentage of the dust remaining when the gas leaves the dust catcher, be removed. The gas is, therefore, quite often put thru tower washers before distribution to boilers, stoves, and metallurgical furnaces, although electric precipitators are used in some cases so as to retain the sensible heat.

The tower washers and electric precipitators referred to above constitute what is known as the primary cleaners, and any further cleaning is done by secondary cleaners. At South Works all the blast furnace gas passes through dust catchers and tower washers and the portion afterwards used in the gas engines is cleaned with Theisen washers, disintegrators, or Cottrell precipitators. For gas engines it is necessary to reduce the solids to less than .01 grains per cubic foot, which is at least as clean as the average air around steel plants.

At No. 1 Power Station at South Works there are six (6) 3375 K.W., three (3) 6000 K.W. gas engine driven generators and three (3) 55,000 c.f.m. gas engine driven blowing engines. The gas for these engines is cleaned by five (5) Theisen washers, two (2) disintegrators, and two (2) Cottrell precipitators. In 1928, when the latest gas engines were installed, it was decided to obtain the increased gas cleaning capacity required through the installation of one Cottrell type electric precipitator having a capacity of 15,000 c.f.m. The chief reason for this installation was the apparent low cleaning cost that could be obtained by the successful application of electrical precipitation.

Previous to the installation at South Works, electrical precipitation had been used successfully in this country for primary cleaning of blast furnace gas but had not been applied to secondary cleaning.

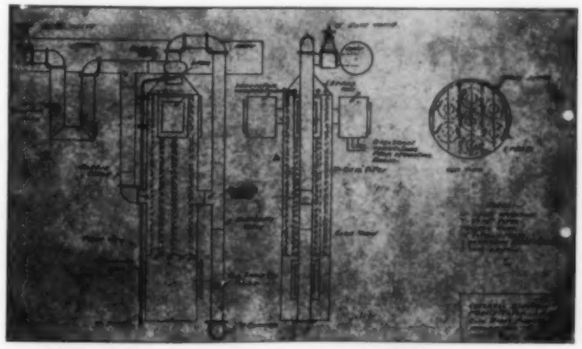


FIG. 1—Schematic diagram of the 2,100 c.f.m. tube type electric precipitator installed at South Works for preliminary testing.

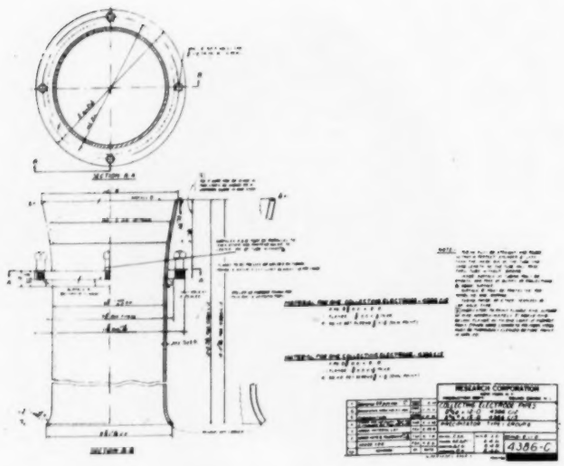


FIG. 2 Detail of the construction of the tubes in the electric precipitator unit.

The first unit was installed at South Works in May, 1929 and was of the plate type. This type was selected since such units were in successful operation in the Birmingham district for primary cleaning. Difficulty was experienced in securing proper distribution of the gas through the machine at all rates of operation and also removing the dirt from the collecting plates as it was deposited. The gas was intended to be distributed by movable vanes installed in the inlet main to the precipitator but, as stated above, distribution was not satisfactory. Dirt could not be removed from the plates because the gas was wet and formed a sludge. The results obtained from this unit suggested that a test unit of the tube type be constructed to determine whether or not if offered opportunities for this particular application by overcoming the difficulties with the plate type.

The Research corporation furnished a tube type unit of 2100 c.f.m. capacity, (Fig. 1) which was installed at South Works and tested over a considerable period of time. This unit consisted of seven (7) tubes, each 8 inches inside diameter and 12 feet long, having a ¼ inch square twisted rod suspended in the center of each tube. The rod served as the negative and the tube as the positive electrode. Gas

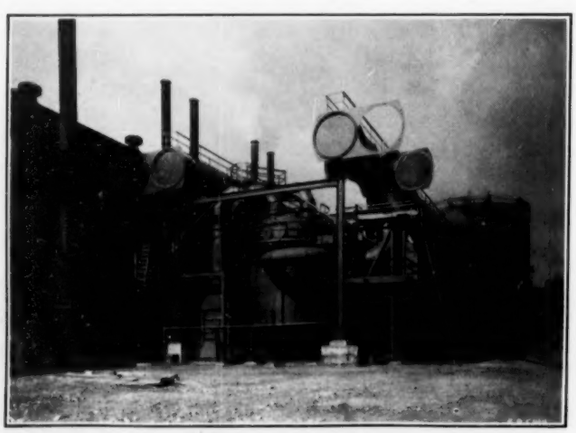


FIG. 3—Electric precipitator installation at South Works, Illinois Steel Company, which is rated at 30,000 c.f.m. of gas.

connections were made in such a manner that the gas could flow either up through, or down through the tube. The upper ends of the tubes were fastened on a tube sheet through which they extended a distance of approximately four (4) inches (Fig. 2). The joints between the tube sheet and the tubes were sealed with a plastic compound, with the result that the upper tube sheet formed a pan which was kept full of water that overflowed the entire inner circumference of each tube and kept the surfaces washed clean. In addition, a series of sprays was installed so that each tube could be flushed with a high pressure nozzle at intervals which were found, by experience, to be about eight hours apart. It was found that if the water was not allowed to overflow the

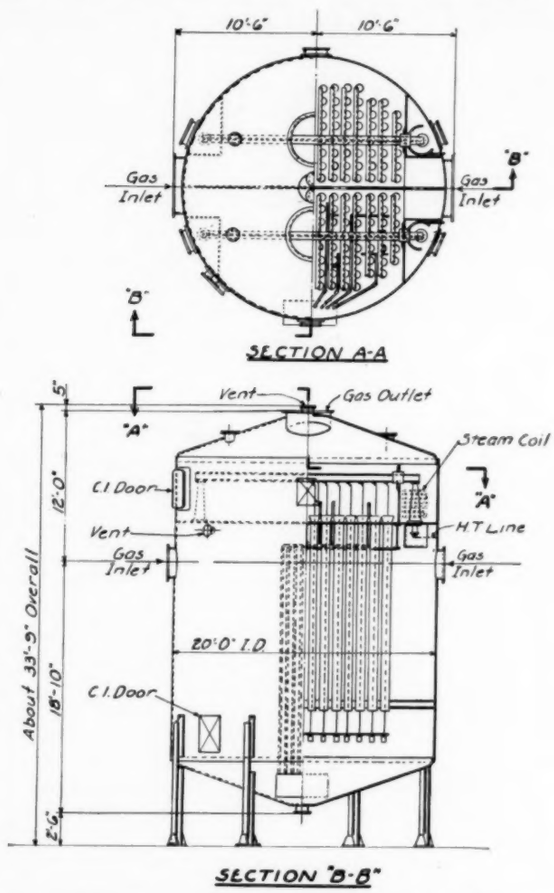


FIG. 4—Diagram showing the construction of the 30,000 c.f.m. electric precipitator installation at South Works.

tubes, dust soon accumulated sufficiently to short circuit the machine. The tests of this unit proved conclusively that uniform distribution of gas could not be secured with gas flowing vertically downward through this type of machine. Uniform distribution was obtained, however, with the gas flowing upward. Tests were, therefore, continued with the gas flowing up through the tubes at various rates of flow and under various electrical conditions.

After comparing the results obtained from these tests it was decided that the two problems of gas distribution and tube cleanliness had been successfully solved. It was found that gas containing .25 grains or less of solids per cubic foot could be suc-

cessfully cleaned to less than .01 of a grain per cubic foot with the use of the 8 inch diameter by 12 foot long tubes, each of which could clean as much as 300 cubic feet per minute.

After obtaining the above results from the test unit, a tube type precipitator, consisting of one hundred and twenty (120) 8 inch by 12 foot long tubes arranged in a circular tube sheet similar to that employed in the test unit, was installed at South Works (Figs. 3 and 4). This was early in 1932. The negative electrode of this unit was also a ¼ inch twisted bar, weighted at its lower end and steadied by means of a light steadying frame (Fig. 5). This unit was designed to clean 15,000 c.f.m. of gas from .25 grains per cubic foot to .009 grains. The results obtained checked those of the small test unit.

It has been found possible to clean 30,000 c.f.m. of gas with this unit or 250 c.f.m. per single tube, continuously from .2 grains per cubic foot to .009 grains per cubic foot with the use of only 7½ horsepower. To obtain this result water at the rate of thirty-five (35) gallons per minute is required for tube cleaning by overflowing the tubes, and every eight (8) hours an additional amount of water at the rate of 250 gallons per minute is used for five minutes to flush the tubes. There is no change in gas flow, power consumption, or cleanliness during this flushing period. Approximately 100 pounds of steam at 15 pounds per square inch pressure is used in this precipitator per hour to keep the insulator compartment dry. This steam is necessary on account of the gas being saturated with moisture which would cause short circuits over the insulators if allowed to become moist.

The cost per twenty-four (24) hours for water, steam, and electric power to clean gas at the rate of 30,000 c.f.m. at commodity prices indicated would be as follows:

	Cost per 24 Hr. Day	Per 100,000 cu. ft. gas
7½ H.P. per hr. @ $ .005 per KWH	$ .675	
100 lbs. steam/hr. @ $ .35 per 1000#	.84	
52,000 gals. water @ $5.00 per Mil. gals.	.26	
	$ 1.775	$ 0.005

The amount of labor required to operate any type of secondary cleaner depends largely upon local conditions. Since there are no moving parts to the Cottrell precipitator it required less attention than either the Theisen Washer or the disintegrator; however, one operator can handle several units of any of these types so a comparison can not be made without knowing local conditions for each individual installation.

FIG. 5—View of the bottom of the tubes showing the negative electrodes and the means of weighting them and holding them steady.

The first cost of an electric precipitator is not out of line with Theisen or disintegrator types of cleaning facilities when cost of buildings, cranes, etc. are taken into consideration. The electric precipitator can be located out in the open but the electrical equipment used in conjunction with it must be housed in a small building nearby. Since all of this electrical equipment is light no crane facilities are required.

The advantages derived from electrical precipitation are as follows:

Continuous and reliable gas cleaning
Low power consumption
Low water consumption
Low maintenance cost
Small pressure loss across the precipitator.

This subject would not be complete without an allusion to the matter of safety. When any machine is used on blast furnace gas it is important that extreme care be taken on cleaning and maintenance work. On the basis of operating results it is believed the amount of maintenance work to be done during the life of the precipitator will be low; nevertheless, it is necessary to take the unit out of service occasionally for inspection and general cleaning. For this reason, when used on blast furnace gas electric precipitators should be so designed as to provide no pockets or corners where blast furnace gas can remain during the cleaning periods. Positive ventilation should be provided during the entire period of inspection or cleaning.

Electrical Precipitators Washed Blast

Discussion by H. M. Pier,

The papers by Mr. Dinius and Mr. Hollett cover the work, which was done at South Chicago, in the cleaning of gas for gas engines. Following the tests at South Works, the small 7-pipe precipitator was moved to the Mystic Iron Works at Boston, and then to the Campbell Works of the Youngstown Sheet & Tube Co. at Youngstown, in order to determine how much gas per tube could be treated to clean gas to the point desired for use in stoves. It was found that whereas for gas engine cleanliness 300 to 350 cu. ft. per tube was about right, for stove cleanliness 450 or even 500 cu. ft. per min. per tube could be cleaned.

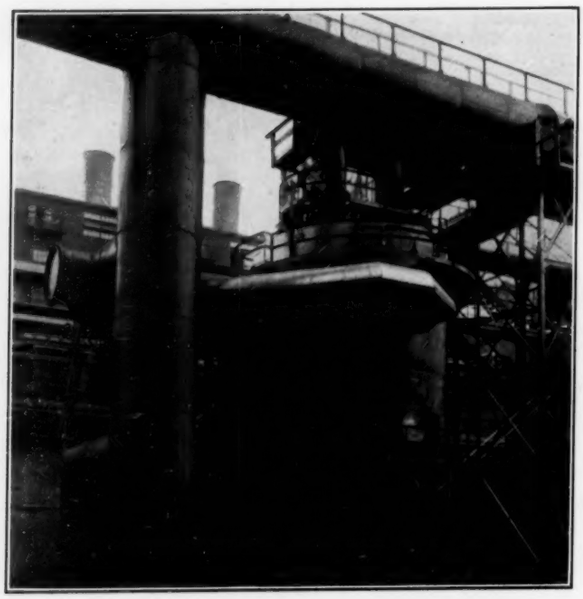


FIG. 1—Electric precipitator installation at the Campbell Works of the Youngstown Sheet & Tube Co.

The next step then was to install a precipitator at the Campbell Works to treat 45,000 cu. ft. per min. (See Fig. 1) This installation went into operation in April, 1931. This was sold and guaranteed to clean that volume of gas from .35 grains per cu. ft. at the inlet to .02 grains per cu. ft. at the outlet. This precipitator consists of 208 pipes, each 8" in diameter and instead of being 12 ft. long are 15 ft. The diameter of the tank or shell is 20 ft., and the overall height about 35 ft. The electrical apparatus, which consists of two complete sets, is housed in a small brick building close to the precipitator. The precipitator is divided at the top into two sections, 104 pipes to each, and each section is connected to its own electrical apparatus. Each set of electrical apparatus, however, is of sufficient capacity to operate the entire unit of 208 pipes in case of necessity.

The results of the tests of this installation show that when treating 45,000 cu. ft. per min. the gas was cleaned to .003 to .008 grains per cu. ft., and when treating 60,000 cu. ft. to .01 to .015 grains per cu. ft. A few tests were made passing a full 40,000 cu. ft. per min. through half of the precipitator. Under these conditions the dust content of the outlet gas was still within the .02 grains per cu. ft. desired.

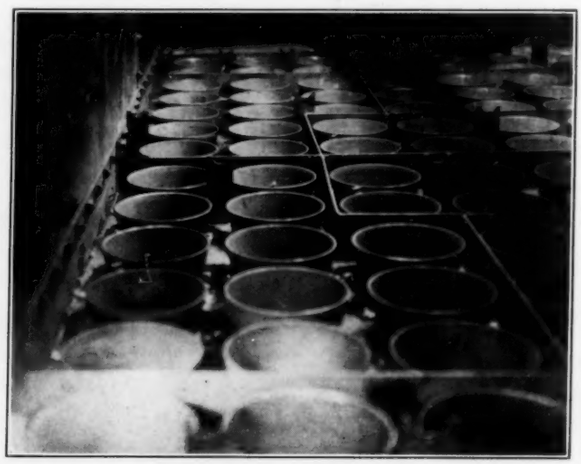


FIG. 2—Top header sheet of precipitator showing the sections into which it is divided for the purpose of properly distributing the flow of water through the pipes.

The power consumption ranges from 20 to 30 kw. The water requirements are about 90,000 gallons per 24 hours, and the steam requirements about 2,000 lbs. per 24 hours, which makes the total cost of gas cleaning just about the same as the figure given by Mr. Hollett.

In order to get an even overflow of water over all tubes, the top header sheet is divided into sections, as shown here. (See Fig. 2.) No more than 13 tubes are included in each section. These 13 tubes are very carefully leveled with each other. Each section has its own individual water supply. This scheme obviates the almost hopeless task of trying to level up the 208 tubes so they will each get their share of water. The overflow of water comes into the pond of each section through pipes which are 2 in. in diameter and the water, therefore, overflows over the edge of each tube continuously.

In order to prevent the slow building up of material on the high tension bus beams over the tubes, sprays are installed at the top of the precipitator so that periodically this upper framework can be flush-

For The Cleaning of Furnace Gas

Research Corporation, Chicago, Ill.

ed. This obviated frequent shutdowns for cleaning, and I understand that the unit at Campbell Works has operated upwards to ten months continuously without being taken off the line.

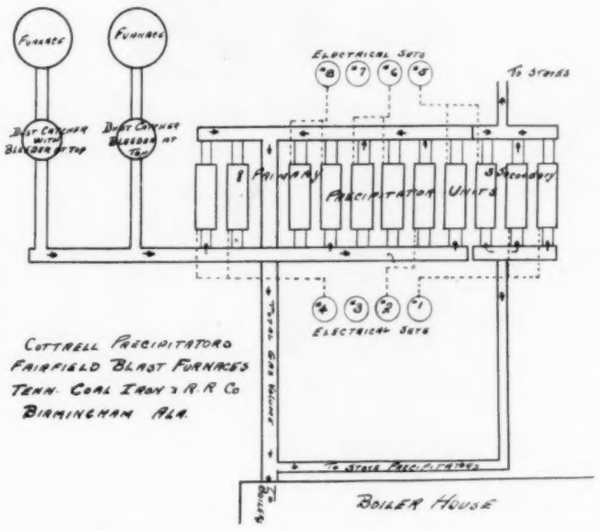


FIG. 3—Dry type of electric precipitator installed at Fairfield, Alabama, Works of the Tennessee Coal, Iron and Railroad Company.

In September of last year an installation of the same size and practically identical in design was installed at the Haselton Furnace of Republic Steel Corporation. This installation was designed to clean 60,000 cu. ft. of gas per min. at standard conditions (68,000 at actual main conditions) from a dust content of .3, and was guaranteed to clean to .025. After the completion of this installation tests were conducted, but, unfortunately, only 56,000 cu. ft. of gas per min. was available for treatment. The dust content at the inlet was .293 grains per cu. ft., and at the outlet .007 grains per cu. ft., from which it is obvious that the installation is easily capable of meeting its guarantees when treating the full rated gas volume.

All the discussion so far has been on the treatment in the precipitator of gas, which has already passed through a primary washer. In other words, the gas is cool and moist, and is in ideal condition for electrical precipitation. There is a wide difference between this application and the treatment of hot dry blast furnace gas. The latter is a much harder task.

Several installations in different parts of the country have been made for the treatment of hot dry gas, the one at Fairfield, Alabama, being a typical example. (Fig. 3.) All of the gases from the two furnaces go through ordinary dust collectors with a bleeder on top of each. The combined gas from the two furnaces then pass through eight precipitator units in parallel. The dust content at the inlet of the precipitators is approximately 3½ to 4 grains per cu. ft., and at the outlet around .3 to .4 grains per cu. ft. Most of the gas goes to the boilers, but that portion used for the stoves is passed through another set of precipitators, three units in parallel, where the dust content is reduced to .08 or .10 grains per cu. ft. There are eight sets of electrical equipment for the entire installation.

The total volume of gas treated is about 340,000 cu. ft. per min. at a temperature of from 400 to 500 deg. F.

The collecting electrodes are concrete plates 2 in. thick spaced 8 in. face to face. (Fig. 4.) There are two sets of plates in series in the direction of gas flow, each plate being 6 ft. 6 in. long. Reinforcing rods are imbedded in the center of each of the plates, as shown on the sketch. These rods are grounded. Midway between the plates are suspended wire discharge electrodes which are connected to the source of high voltage power. The dust is precipitated on concrete plate collecting electrodes, from which it is removed by scraping once in 24 hours. The scraping is accomplished by passing chains, as shown on the drawing (Fig. 5), over the face of the plates. The chains are all operated from an air cylinder.

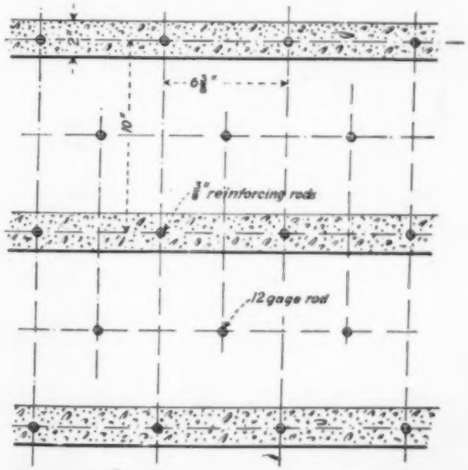


FIG. 4—The collecting electrodes are concrete plates designed as shown.

Each unit is equipped with goggle valve and butterfly valve, so the distribution of gas can be controlled, and any unit can be shut off without disturbing the operation of the others.

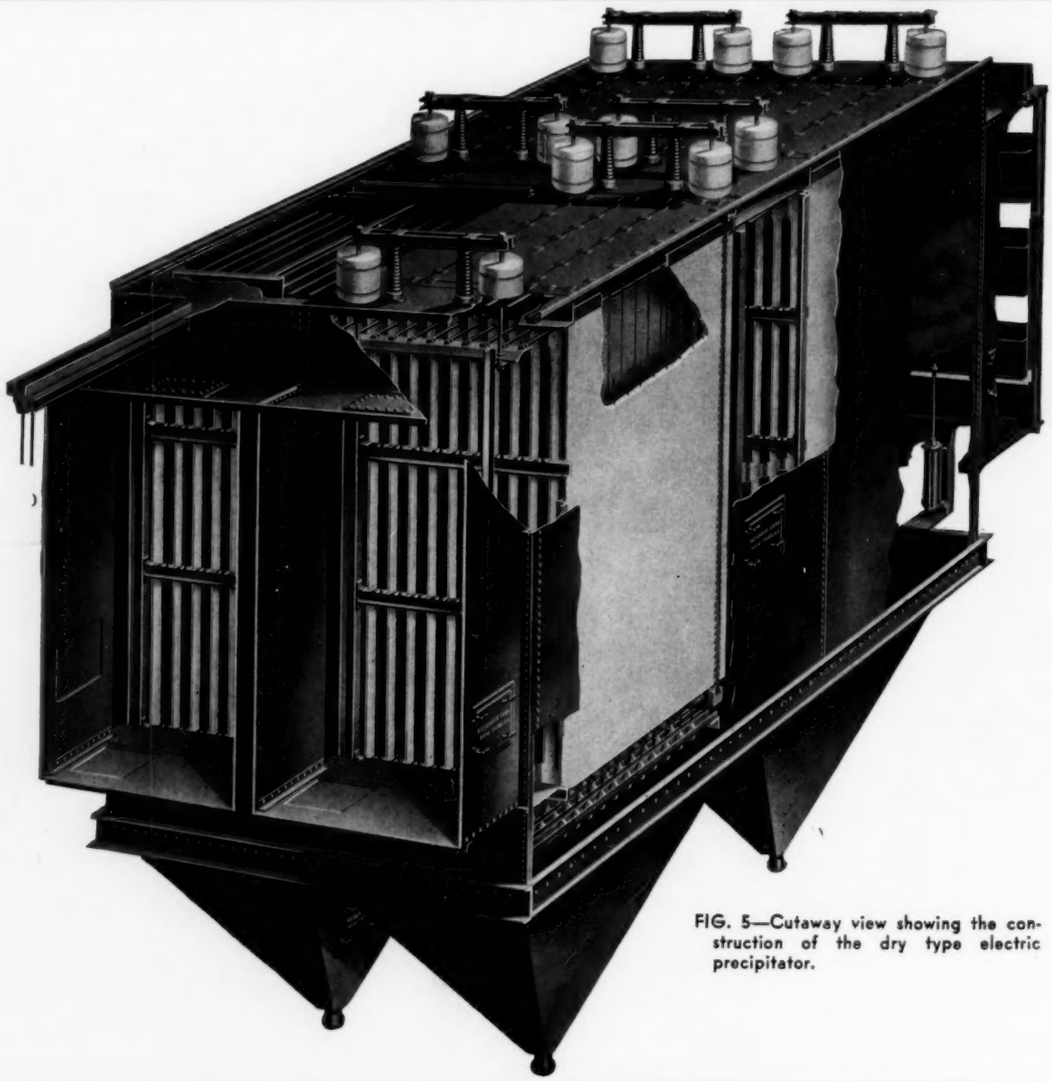


FIG. 5—Cutaway view showing the construction of the dry type electric precipitator.

Discussion

Discussion Presented by

S. F. X. Plaisance, Engineering Dept., General Electric Company, Chicago, Ill.
J. C. Haynes, Combustion Engineer, Freyn Engineering Company, Chicago, Ill.
G. T. Hollett, Steam Engineer, Illinois Steel Company, South Chicago, Ill.
H. M. Pier, Research Corporation, Chicago, Ill.
E. Kieft, Engineer of Tests, Illinois Steel Company, Gary, Ind.
A. J. Whitcomb, Electrical Engineer, Freyn Engineering Company, Chicago, Ill.
Gordon Fox, Vice President, Freyn Engineering Company, Chicago, Ill.
C. N. Arnold, Steam Engineer, Youngstown Sheet & Tube Company, Indiana Harbor Works, Indiana Harbor, Ind.
R. Lindgren, Asst. Blast Furnace Supt., Wisconsin Steel Works, International Harvester Company, South Chicago, Ill.
H. A. Smith, Blast Furnace Master Mechanic, Illinois Steel Company, South Chicago, Ill.
W. E. Miller, Electrical & Mechanical Supt., Bethlehem Steel Company, Johnstown, Pa.
K. E. Dinius, Chief Testing Engineer, Illinois Steel Company, South Chicago, Ill.
J. W. Murphy, President, J. W. Murphy Company, Chicago, Ill.
S. A. Kish, Chief Electrician, Youngstown Sheet & Tube Company, South Chicago, Ill.

S. F. X. Plaisance: The question has often been asked just why the discharge electrode is always made negative, and it may be of interest to discuss this briefly.

The breakdown between a needle point and plate will occur at widely different voltages, depending on whether the point is positive or negative. For 2 mm. spacing the breakdown voltage is the same for either polarity of the point. At shorter distances, the arcing voltage is greater when the point is positive. For all spacings above 2 mm. the arcing voltage is greater when the point is negative. This means that with a given gap, the voltage can be raised to a higher value, without arcing, if the point is negative.

For best results in electric precipitation, it is important that the voltage be raised to the highest value without arcing, so this is one reason why the discharge electrode is always made negative.

Another consideration is the so-called electric wind from a highly charged point. Ions having the same sign as the point are caused by the intense

field to move away at a high speed, and to cause secondary ionization by colliding with molecules of the surrounding gas; all these ions, moving rapidly away from the point, carrying air molecules with them, cause the electric wind and a corresponding mechanical reaction on the discharging conductor. This shows the desirability of using a high voltage if the wire is to be kept free from deposits, and also of having the wire negative because electrons and negative ions are readily formed and have a higher velocity than positive ions.

The corona differs, according to whether it is positive or negative. The positive corona consists of fine, bluish-purple brushes, and if the potential is sufficiently high, the wire is covered with a bluish-purple film. On the other hand, the negative corona consists of bright, stationary, reddish discharges and the wire is not covered with a glowing film. The corona is distributed more evenly about the active electrode when it is negative.

Another reason is that a wire electrode often vibrates when its potential is raised nearly to the sparking point, and this effect is more violent when the wire is positive.

Still another reason is that the loss from a positive corona is greater than from a negative corona.

Up to quite recently, the mechanical-commutator type of rectifier has been the most widely used. This device consists of four stationary arms spaced 90 deg. apart with conducting tips on the ends, and a set of four revolving arms driven either from extended shaft of motor-generator set, or by a separate synchronous motor. Since the alternating voltage passes through zero value 120 times per second, rectification will be obtained if the connections to the external circuit can be interchanged 120 times per second, provided this interchange is made at the moment when the voltage or current is zero. For this reason the rectifying device must be synchronized in relation to the voltage.

The mechanical rectifier of the revolving arm type, while simple and rugged, introduces some problems. It makes and breaks the circuit twice in each cycle, and since the spacing of adjacent rectifier shoes must be sufficiently great to withstand the full transformer voltage, only a portion of the entire a. c. wave can be rectified, and the make and break can occur well up on the current and voltage waves, and not at their zero values. Furthermore, the rotating arms do not actually come in contact with the stationary shoes, but have about 1/16 in. gap, the current arcing from shoe to arm. Therefore, there are always four arcs in series in the circuit. The treater itself has a large electrostatic capacity, which in combination with the inductance in the transformer windings and circuit, may give resonance conditions. The combination of high frequencies and voltages puts severe strains on the insulation of transformer windings. The wave form is also considerably distorted by this type of mechanical rectifier.

The vacuum tube depends for its operation as a rectifier on the fact that when two electrodes, one of which can be heated, are placed in a highly evacuated container, current can flow through the space separating them, only when the heated electrode is negative. When such a tube is placed in an alternating current circuit, it rectifies this current by allowing it to pass during one-half wave and suppressing it during the next. By using two or four tubes suitably connected, both half-waves can be rectified.

The rectified current wave obtained from the tube rectifier is much smoother and more uniform than that obtained from the mechanical rectifier, and hence imposes less severe service on the transformer. It has also the advantage of being a device without moving parts.

The efficiency of the tube is high, as the voltage drop between anode and cathode is about 500 to 1500 volts, while the energy required for heating the filament is less than 500 watts per tube.

The life of a tube depends on the life of the filament, and this life is constantly being improved. The average life of a tube is about 3,000 hours, but many of the later tubes have exceeded this figure.

In 1930, we supplied the Anaconda Copper Mining Company two tube equipments, each rated 25 k.v.a., 50,000 volts, 500 milliamperes. Two Kenetron tubes rated 100,000 volts, 250 milliamperes were used on each for full wave rectification. Overload protection consists of a relay of the reclosing type so that a short circuit in the treater might relieve itself before the equipment was locked out, which is done after three operations.

These equipments were supplied to supplement their mechanical rectifier plant, and as a working trial for the equipment with the idea of ultimately replacing their mechanical rectifiers with Kenetron rectifiers,, but business conditions held up any further installation work.

These units were originally installed on a smelter stack taking gases from zinc roasters. For the same service and rating, the results obtained were somewhat better than with the mechanical rectifiers. Some of the tubes had operated over 4,000 hours before the plant was shut down.

J. C. Haynes: I would like to know if the flow of gas increases suddenly or is the amount passing through the precipitator very closely controlled?

G. T. Hollett: At the installation at South Works the flow of gas is fairly constant. The flow is regulated by keeping a definite differential across the precipitator. The precipitator is located a considerable distance from the blast furnaces, and the pressure is fairly constant. The variation of flow at our installation is not as great as would be expected at installations adjacent to the furnace, and where all of the gas produced at the furnace passes through the precipitators as it does at the T. C. I. installation.

E. Kieft: Mr. Chairman, I would like to ask about the starting up and stopping conditions, and also the danger of explosions.

H. M. Pier: If there is an explosive mixture in the precipitator when the current is applied, there may be an explosion. Corona discharge in itself will not cause an explosion. There must be an arc to explode an explosive mixture, but arcing is likely to occur in the precipitator at any time. Therefore, care must be taken to see that all the air is purged from the precipitator before power is applied.

A. J. Whitcomb: I would like to ask a couple of questions. In maintaining the electric precipitator, there may be some danger of corrosion. As I understand it, these tubes are nothing but steel tubes. I would like to ask Mr. Pier and Mr. Hollett what experience they have had with corrosion, not only of

the tubes but also possibly the electrodes. Possibly they use some anti-corrosion or corrosion-resisting steels, or maybe they recommend something that will resist corrosion.

I would also like to know whether, in their experience, they have noticed any chemical reaction caused in the blast furnace gas by the corona discharge. It is sometimes necessary to go inside of the precipitator for maintenance and repair work. It is necessary to purge it out with steam to make it safe for a man to work inside of the precipitator tank. Blast furnace gas can generally be purged successfully. It is difficult to purge a heavier gas, a gas like cyanide, for instance. Is there any possibility of blast furnace gas having some chemical reaction with high voltage corona discharge that would produce a heavy gas that would be difficult to purge from the equipment?

G. T. Hollett: We have had some difficulty with ¼ in. electrodes corroding at the point of their contact to the upper framework which holds the wires or rods. If the connection is not good at that point, there is electrolytic action which will cause some corrosion in time. We are using twisted iron rods. In two years of service some of them have failed. We have had no trouble with the other parts of the precipitator showing any chemical action or corrosion.

H. M. Pier: As far as I know, there is no evidence of corrosion of the tubes. I have not heard of any, if there is. Before the installation is put in service we do what we call "de-greasing", which is simply the treatment of the tubes with an alkali, so there will be an equal distribution of water. Otherwise there is no treatment given to the tubes whatever.

As for discharge electrodes, there have been, I should say, four or five of these ¼ in. rods that have given trouble. It is not due, in my opinion, to chemical action, but is due to the fact that these electrodes are held in place at the top by a pin, which passes through a small hole in the rod, the pin fitting loosely through the hole. Probably there is, therefore, some slight voltage differential, which has gradually weakened the rod at that point. This has been corrected by welding the rod to the centering clip and eliminating the pin entirely.

A. J. Whitcomb: Would you recommend a corrosion-resisting material or anything of that nature?

H. M. Pier: Why should we if there is no corrosion? From an electrical standpoint any metal could be used. The choice of metal is purely a matter of cost. As for cyanides, I do not believe that there is any chemical action taking place in the precipitator, because the gas is not in the field long enough. Even on installations for sulphuric acid plants where all the necessary elements of oxidation are present, we have never been able to detect any conversion of SO_2 to SO_3 as the gas passes through the precipitator. I doubt very much, therefore, whether it would be possible to have any re-action in the precipitator due to the electrical discharge, which would change the chemical composition of the gas and form any compound, such as cyanides.

A member: What are the sizes of the tubes?

H. M. Pier: 8 in. inside diameter. Those at South Works are 12 ft. long, and those at Youngstown 15 ft. long.

Gordon Fox: To what extent, or what relationship has been established in cleaning cold gas between the dirt content of the incoming gas and the capacity of the tube?

H. M. Pier: If the incoming gas contains .3 grains per cu. ft., and the outlet gas is to contain .02 grains per cu. ft., each pipe could treat approximately 300 cu. ft. per min. If the incoming gas contained .2, each pipe would handle approximately 350 cu. ft. per min. to the same degree of cleanliness. I am giving you this from memory, but it is approximately correct.

C. N. Arnold: I was going to ask Mr. Hollett what precaution they take during the course of the day's operation of the precipitator to check up and see that the precipitator is turning out clean gas.

G. T. Hollett: When we first put in the precipitator we did considerable testing. It is a difficult and costly job to get a sample which is large enough to really show accurate dust content so we worked out a short-cut method where we use filter paper in a tar camera. We have made up standard filter papers with a definite amount of gas going through each of them. The standard filter papers were made by passing a definite amount of gas of known dirt content through the filter paper. Various amounts of dirt were deposited on different papers by changing the amount of gas passing through the papers until a set of filter papers were produced that represented the results of the dirt collected by passing a definite volume of gas with varying dirt content. With these filter papers as a standard we could determine by matching colors of the samples taken the dirt content of a sample.

Gordon Fox: Every hour?

G. T. Hollett: We don't take samples that often. It is not necessary.

R. Lindgren: I would like to ask whether, just prior to the flushing out period, isn't there more or less of a continuous arcing in the machine? If that is the case there might be an explosion if the gas pressure dropped sufficiently to permit infiltration of air. By flushing out every six hours, would that do away with the arcing?

G. T. Hollett: In our case we are flushing every eight hours, and there does not seem to be any arcing at all. In order to have an explosion there must be air in the precipitator, and since the installation is always under pressure, there is no opportunity for air to get in.

H. A. Smith: In other words, you don't have a suction on the other end.

G. T. Hollett: Special precautions have been taken. We could not take a chance of operating below atmospheric pressure.

A member: Do you purge with steam?

H. M. Pier: Some just let gas go through for a time.

W. E. Miller: I don't know much about the precipitation process of cleaning gas, since all of our gas cleaning is done with disintegrators. I have been wondering however, when arcing takes place, if there is any interference with radio or telephones.

K. E. Dinius: We have never had any trouble at South Works. Our installation is located some distance from any residential district where radio sets might be effected, and we have never noticed any disturbance on the telephones in the plant. The high

resistor units in the rectifier circuits are designed for damping out oscillations which might cause telephone or radio disturbances.

H. M. Pier: There was a time when the precipitator circuit on some installations caused considerable interference with radio reception when radio was in its infancy. That made it necessary to develop a special tube, which was used on those installations, which showed radio interference. These tubes are inserted in each of the four legs of the rectifier, and they dampen out the oscillations, which interfere with reception. With these tubes in service it is impossible to tell whether the precipitator is operating or not.

C. N. Arnold: I have a question I would like to ask Mr. Hollett and that is, if you purchased a precipitator for a certain guaranteed capacity and you found that the supply of gas you have is limited, is the precipitator so constructed that you can test say half a section of the precipitator on the gas supply that you have? In other words, can you test a precipitator with an insufficient quantity of gas?

G. T. Hollett: Yes, on the one we have we can do that.

C. N. Arnold: Would you get full rating on the half sections?

G. T. Hollett: No, we cannot do that. The gas flows through ours and it would have to be on all the tubes or through none.

H. M. Pier: The two installations at Youngstown are each split in half at the top with a dividing plate between each half, and a gas outlet for each half. Each gas outlet is equipped with a butterfly damper. Therefore, half of the unit could be tested with as much as might be available.

A member: I would like to ask what the relative operating cost is when handling dry gas and the moist, cool gas.

H. M. Pier: I would say that the cost of dry gas cleaning per unit of gas volume would be about three or four times as great as with cool gas.

E. Kieft: I would like to ask whether the same method can be applied for other gases, such as hot producer gas and coke oven gas with the same efficiency; also I would like to know the relation between the temperature and the efficiency.

H. M. Pier: Do you mean at 1400 deg. F.?

E. Kieft: Yes.

H. M. Pier: We cannot treat gas at temperatures as high as this because we cannot find suitable materials of construction to stand up. There is no reason to believe that the electrical effect would not occur at those temperatures and it is, therefore, purely a matter of materials of construction. The upper limit seems to be about 1100 to 1200 deg. F.

We can clean hot producer gas, but this is not an easy job and the precipitator is quite expensive.

E. Kieft: Well, I guess we'll have to wait a while.

H. M. Pier: If producer gas is cooled to a temperature of about 90 to 100 deg. F., then the precipitator can be used for the removal of tar and it operates very nicely, but in order to accomplish this purpose the gas must be cooled.

J. W. Murphy: How do you remove the tar from the plates?

H. M. Pier: The tar is free flowing. It runs down the tubes in a continuous stream, and no rapping or flushing is necessary.

C. N. Arnold: What is the practice at South Works on spares? In other words, if you have one in operation, do you have a spare on hand? What happens when one goes out of commission?

K. E. Dinius: As far as the electrical equipment is concerned each unit is of sufficient capacity to operate both precipitators at one time, and is so arranged with disconnect and transfer switches in the high tension lines, that either or both precipitators can readily be transferred to either set of electrical equipment. Thus in case of trouble on one unit, that precipitator can be switched over to the other unit while repairs are being made. It is hardly necessary to carry additional spares.

G. T. Hollett: The two precipitators we have there work in parallel with five Theisens and two disintegrators. When any of the Theisens or disintegrators are in service we have a greater pressure on the discharge main than on the inlet main which compels us to operate the fans.

S. A. Kish: Well, I didn't come over here this evening to compare figures but I might say something about our little equipment. We have tube rectification operating about three months and doing very well and, as I understand, very efficiently. I might say that we have had our precipitator on right now without any disturbance for the last two weeks. It seems to be working very satisfactory. Anything more than that I am not able to say yet.

H. M. Pier: There has been some little discussion about the use of tube rectifiers instead of mechanical rectifiers, and I hope that in the few remarks I have to make I do not step on anybody's toes. We will admit that the mechanical rectifier is noisy, that it has moving parts and that it takes up a little more room than the tube rectifier, but there are two or three other points that should be analyzed.

The first of these is the fact that there is no difference in the efficiency of a given precipitator whether it is energized with mechanical rectifier, tubes or the Girven generator (which is a machine for developing 75,000 volts d. c. with an absolutely straight line). We have made tests on several different types of precipitators, and, as far as we can find, it makes no difference what type of rectifying apparatus is used.

The second point is the matter of initial cost. On small jobs; that is 5,000 or 10,000 cu. ft. per min., the advantage is in favor of the tube rectifier, but on the larger jobs where the volumes are 30,000, 50,000 or 100,000, or more, the advantage is in favor of the mechanical rectifier, although there is not much difference one way or the other.

The third point is the matter of maintenance. I have some figures, as a result of our study, on approximately 400 mechanical rectifiers that are now in service. Many of these are operating 24 hours a day. Some are on acid plants where the atmospheric conditions are far from ideal; some on tar precipitators; some on blast furnace gas and others on a variety of other types of installations. The average cost of replacement of rectifier parts is $11.90 per year per rectifier. Let us be conservative and call this $25 per year per rectifier. On installations such as those described tonight, there are two rectifiers in

service, which means about $50.00 per year.

To compare with this, four rectifier tubes would be necessary. I understand that tubes of the capacity and voltage for this service cost about $240.00 each, or a toal of $960.00 for four. If the tubes last 3,000 hours, which is a third of a year, the cost of tube replacement would be $2,880.00 per year, as compared with the $50.00 for the mechanical rectifier. If the tubes last 4,500 hours, the replacement cost will be $1920.00, and if they last a full year, the replacement is $960.00.

We have no objection whatever to the use of tube rectifiers. In fact, we are installing them in some cases now, but the question of maintenance cost should not be forgotten in comparing these two types of rectification.

A member: What are the characteristics of the precipitated dust as compared with the regular dust catcher?

G. T. Hollett: The character of the dust would be no different. If you could take it out by washing you would have the same dust that is obtained from a precipitator.

K. E. Dinius: Perhaps Mr. Fox would like to tell us about some installations in Europe.

Gordon Fox: I believe that there are about eight or ten electrical precipitator installations in Europe. They are of three principal types, namely, Elga, Siemens-Schuckert and Lurgi. The Elga and Siemens-Schuckert are alike in that both are single stage cleaners. However, the Elga precipitator is of tube type while the Siemens-Schuckert is of the plate type. They both use hot dry gas but not as hot and not as dry as is used at Fairfield. The Siemens-Schuckert and the Elga installations precondition their gas by putting a certain amount of water in it and cooling it down to about 100 deg. C. or 200 deg F., that is, a little bit above the dew point. You might say that it is half way between the hot Fairfield gas and the cold gas such as at the Youngstown and the South Works installations. The gas goes through the dust catcher, then it is preconditioned in this way, goes through the single stage electrical precipitator and is discharged as a warm, clean gas. It comes out at about 200 deg. F. It is just a little above the dew point. The precipitation is most effective when the gas is saturated or nearly so. The trick is to get the gas as nearly as you can to the dew point without actually reaching it. A considerable amount of difficulty has been experienced because of the large areas of the precipitators which are exposed to the cold weather. This sometimes causes a cooling of the gas in the precipitator itself and that causes moisture to be released. The difficulty is that the dry, flocculent dust which is precipitated on the plates or tubes become moist enough to cake. It does not run down the tube or place as it does in a wet type secondary precipitator.

In the Elga and Siemen-Schuckert installations it is necessary to rap the plates or tubes from time to time in order to cause the precipitate to fall off by gravity. Because there is only a single stage of gas cleaning, the tubes cannot be rapped while the precipitator is working so it is necessary to by-pass the units one at a time to clean them.

One of the difficulties experienced is the fact that the clean gas is delivered at a temperature above air temperature but in a condition nearly at the dew point. As soon as this gas goes into the distribution system and cools down, it is pretty sure to throw out its moisture and you have a certain amount of sludge in your clean gas mains. These precipitators are in units of rather small capacity such as 15,000 cu. ft. per minute. Several units are placed in parallel and there has been considerable difficulty in getting the gas to divide equally between the various units which are located along the main. There is a non-uniform distribution of gas through the various units. These precipitators ordinarily deliver gas around 0.01, 0.02, 0.03, 0.04 gr./cu. ft. or in that neighborhood, the results depending more or less upon the conditions of operation.

The Lurgi precipitator is considerably different. The Lurgi has two principal differences from the other two. First, it is a two-stage precipitator; second, Instead of having a large number of small units operating in parallel, each stage is one big unit. This gets away from the difficulties of dividing the gas among a number of small units. In the Lurgi precipitator, the hot gas is conditioned by putting a small amount of moisture in it, cooling it down and nearly saturating it. As there is a second stage, it is not necessary to get the gas quite so clean in the first stage. After the first stage of electric cleaning, the gas goes through a wet scrubber. Here it is completely cooled down and saturated. Then it goes through a second stage of precipitation which does the fine cleaning and eliminates the moisture. The Lurgi delivers a very clean gas, 0.01 - 0.005 gr./cu. ft. and sometimes considerably less. The gas is cold and there is no difficulty of water in the clean gas mains. It has the advantage that if anything happens at one stage, the other stage functions and gives you a moderate cleaning anyhow. While the Lurgi does a good cleaning job, it is expensive and takes a lot of space. It is difficult to justify the high cost of the electrical precipitation method for the primary cleaning stage as used by Lurgi.

Electric precipitation is particularly attractive in the Soviet Union because at a number of Russian plants there is a scarcity of water and electric power is relatively expensive. The Russians are developing an electrical precipitator of their own. They have designed and manufactured it, and are installing it at two plants, Tula and Lipetsk. Both plants will be started up this year. These units combine a static tower for primary cleaning, followed by a single stage precipitator, somewhat along the lines of the practice at South Works except that both primary scrubber and secondary precipitator are placed in one cylindrical receptacle.

C. N. Arnold: I think before the meeting is closed, I would like to bring out that our precipitator discussed so far is located at Youngstown at Campbell Works. We have another precipitator installed at the South Chicago Works of our Company. From the discussion tonight, electrical precipitators consist of a large number of relatively small tubes, possibly 8" in diameter. The particular one we have in operation in this district is equipped with a small number of tubes but of a large cross section. In other words, our sections are about 40" in diameter and four in number. I wish to bring out the difference in design between the two precipitators in use at the two plants of the Youngstown Sheet and Tube Company.

S. A. Kish: Do you have a single discharge electrode inside the tube?

C. N. Arnold: The electrical discharge surface is a series of fins attached to the outside of each tube. This is extremely difficult to describe without a sketch.

S. A. Kish: This tube, I should judge, is close to 4 ft. in diameter and spaced saw-blade edges placed vertically all the way down and the distance between that and the collecting rod is 3½ in. That is supported on a top insulator.

A. J. Whitcomb: How is the gas discharged, is it passed across the electrode?

S. A. Kish: Yes, there are four ways, four different openings. It comes in at the inside of the discharge electrode and goes out the openings, about four sections.

K. E. Dinius: I would like to ask Mr. Fox if he finds that electrical precipitation is used more generally in Europe for blast furnace cleaning than it is here.

Gordon Fox: I think it was used earlier there than here. I don't know if there has been any increase in the last few years but there were many sizable installations there before here. I think there are about eight or nine good size installations there and about four or five over here now. If the installations in the two trial plants in Russia are successful, there will probably be quite a few installations in Russia.

Steel's Part In National Recovery

By WALTER S. TOWER

Describing the part played by the steel industry in the national recovery, Walter S. Tower, executive secretary of the American Iron and Steel Institute, in a nation-wide NBC radio address, warned that any return to the destructive cutthroat conditions that formerly prevailed in this industry might be fatal to the whole recovery effort.

Mr. Tower said that since last June the steel industry has re-employed more than 80,000 people, has raised wages approximately 36 per cent, has eliminated unfair practices and price discriminations and has increased prices moderately to support the labor provisions of the code.

"In fairness to its employees and to its stockholders, the industry must earn a reasonable profit," Mr. Tower said. "If a profit is not earned, many steel companies will eventually go out of business and employees will lose their jobs.

"Since last June, over 80,000 people have been added to steel company payrolls. Furthermore, on April 1, a further addition in wages became effective throughout the industry, making a total advance in hourly wage rates since the code of approximately 36 per cent. The April 1 advances are adding approximately $36,000,000 annually to the industry's payrolls."

"Hourly wage rates in the steel industry are now from 6 to 7 per cent above the wage peak of 1929. Meanwhile, however, prices of steel products have not advanced nearly as rapidly as wages.

"Price increases have not been sufficient to put the industry upon a profitable basis as yet. This is a matter of some concern to the stockholders among whom the ownership of the iron and steel industry of the United States is divided.

"It is estimated that eleven leading producers of steel had a combined net loss in 1933 and 1932 of $180,000,000. This money was not lost by the men who run the mills. The steel mills are owned by their stockholders, 500,000 of them scattered all over the United States in all walks of life. Today the executives in the iron and steel companies are in the main only hired help exactly as workers in the mill are hired help.

"Executives, therefore, now possess a dual responsibility: first, that of maintaining satisfactory wages and a broad spread of employment among the workers and second, that of securing, when and if possible, a rate of earnings which will secure fair dividends for the stockholders."

Collective bargaining in the steel industry has been in effect in some plants for fifteen years, Mr. Tower said.

"The great majority of workers are now participating in employee representation plans in their respective plants. Thousands of workers have utilized the facilities and benefits available under this method of collective bargaining."

A survey made by the American Iron and Steel Institute of employee representation plans during the first four months of operation under the steel code was pointed to by Mr. Tower as evidence of how these plans are meeting the problems arising in the day's work.

"There was actual collective bargaining between employees and management in thousands of cases considered with the result that employees' requests were granted in 70 per cent of such cases."

Mr. Tower listed the major accomplishment of the steel industry under the code as the raising of the wage rates of nearly half a million people in spite of the fact that the industry as a whole is not yet able to earn any profits for its stockholders.

Heat Resisting Castings

By DR. F. A. FAHRENWALD
Chicago, Ill.

Presented before the Combustion Engineering Division of the A. I. & S. E. E. at the Spring Engineering Conference held in Youngstown, Ohio, April 11 and 12, 1934.

The object of this paper is to outline a narrow practical analysis of all the various factors concerning heat-resisting alloys which have to be considered in any contemplated industrial high-temperature use of these materials and to present a brief commercial interpretation and simplification of widely scattered and somewhat discordant data relating to this subject.

Various technical committees and numerous coworkers are daily turning out precision grist from the research mills of many laboratories but much of this is not easily usable by the practical plant man responsible for the introduction of every latest tool into operations under his immediate control.

What is offered herein is mostly culled from engineering data which my organization has used for some years in the design of high temperature equipment and includes brief discussion of some relationships and empirical findings which my own activities in this field have indicated to be important in determining proper selection of alloy compositions and mechanical designs for high temperature service.

Some of this is so obvious and well known that a discussion thereof is hardly justified even in a general summary but it does permit an easy survey of the subject as a whole. On the other hand some statement contained herein may not meet with general acceptance, but refutation will require an actual truth to take its place.

There is much in this field in the present stage of development which practically precludes precise anticipation of all variables to be encountered in final operations and often only the judgment of experience can serve to avoid difficulties. Even were complete precision data available, it must be strongly emphasized that heat-resisting alloys are mere raw materials with which to build and that final success of a high temperature alloy mechanism is dependent, even more than in structures of steel or stone or wood, upon the ingenuity of man in properly adapting the material to his use, and there is no more connection between the characteristics of heat-resisting alloys and their proper design into high temperature mechanisms than there is between the properties of sheet steel and the stream-lining of automobiles.

As compared with accumulated data concerning normal temperature properties of iron and steel, or other long used materials, there is relatively little in the way of generally available condensed working information upon which to base specifications for materials or designs of metallic structures to function at high temperatures.

Extensive verbiage has been expended upon this subject and the lack of common agreement in much of this has resulted in a degree of confusion which is hindering the proper development of processes dependent upon the successful use of heat-resisting alloys.

In view of the considerable controversy in this field, I shall confine this paper to a presentation of personal conclusions drawn from my own experiences in the development and production of heat-resisting alloys and in the design and building of high temperature alloy equipment and will include only data which have been found dependable in the engineering of successful commercial installations of alloy castings of my own development or production. Even though directed specifically to this series of alloys the data presented herein must, of course, apply to similar grades of alloy from whatever source **provided** the same care and precautions are observed in the foundry practice, in the selection of raw material,—in the design of unit castings and operating assemblies and especially, if all the hereinafter described effects of variation in analyses are given full weight. Among all factors which contribute to successful high temperature performance soundness of castings as dependent upon foundry practice must be given the position of first importance.

No claims are made for mysterious practices nor for the secret nostrums so often vaunted in this field which are supposed to impart magic qualities to castings without leaving determinable traces.

It is, however, emphasized that the design of high temperature alloy units involve many important features which are not encountered in ordinary engineering practice, such as phase changes, wide limits of expansion and contraction—decreasing strength with increased temperatures—need for proper temperature distribution and gradients within alloy sections—and the like.

Several overgrown textbooks would be required to thoroughly treat a subject as wide and complicated as this one of heat-resisting alloys, so a brief offering of this nature can only give a sketchy review of the factors which have proved most useful in the technical foundation upon which a successful alloy business has been built.

Chromium-containing alloys for high temperature service have been available for more than 25 years, (originating in a commercial way with resistance wire heaters in 1906) and the past 15 years have seen numerous investigations into their compositions and properties, so it would seem that present day buyers specifications covering analysis and design of heat-resisting alloy assemblies should be governed by a rather sound knowledge concerning the utility and limitations of this class of materials. Such is not the case, however, and the many astonishingly false conceptions which still exist regarding the actual and relative high-temperature performance ability of these alloys are exemplified by the numerous requests for unworkable combinations which are received by alloy producers from purchasing and designing engineers of many industries.

Volumes (1) of mixed theory and facts relating to this subject are scattered throughout the literature

(1) See particularly "symposium on effects of temperature on metals A. S. T. M., 1932, and the A. S. S. T. Hand-book on Alloys."

but most of this is either too general or too involved with hair-splitting discussion of creep limits, time-temperature stress deformation factors, and the like, with very little in the way of collected, properly interpreted, working information as to what actually can or cannot safely be done under a given set of conditions. A vast amount of data of a more precise nature, particularly precision values for high temperature strength, still remain to be uncovered but the **general** relationship of analysis to both physical and chemical properties of alloys as well as the **relative** industrial performance values of alloys within a wide range of compositions, are now sufficiently well known to suitably answer most queries relating to prospective uses or to reject those requests which call for a combination of properties which are contrary to the laws of nature.

Much of the lack of agreement among various manufacturers, engineers and users in a field so relatively new is due to views from different angles and may be likened to the bitter arguments of the six blind men who could not agree as to what an elephant looked like—whether a snake, a fan, a tree, a spear, a wall or—as was loudly proclaimed by the sixth (who had touched only the elephant's tail) "exactly like a rope." This controversy arose because each had contacted a different part of the animal.

In view of the general nature of this discussion it may not be out of order to include a few remarks concerning the buyers part in this subject of mutual interest, and to suggest that he go see the elephant for himself instead of depending upon the widely divergent tales of men who have touched only a small part of an extensive exposure.

The usual buying practice has been along about the following lines:*

(1) To send out bids for quotations on "an alloy suitable for the application herein described" with the requirement that the manufacturer furnish a service guarantee.

(2) To specify physical properties without reference to analysis.

(3) To send out specifications covering all details of both analysis and design.

(4) To specify design and an analysis together with physical and chemical properties or—

(5) To ask for this fourth list plus a performance guarantee.

In the first case he may receive quotations from a dozen bidders each on his own special "grade" of alloy, which is "guaranteed" suitable, and in this case the lowest pound price has usually taken the order, notwithstanding the fact that the highest quotation per pound may have covered a product which in the end would have been far less costly on a piece price or a service unit basis. This practice also places a competitive handicap on the vendor who stands by his guns on a quality basis. The second has often asked for strength values impossible to secure in any alloy. The third method is the best provided the buyer knows what he needs, and in this case he is entitled to a guarantee covering analysis and workmanship.

The fourth case has often designated an analysis which could not yield the specified physical or chemical characteristics. Comment on the fifth type is hardly needed, but such requests often are received.

Many specifications are also sent out by a careful purchaser whose testing engineers have applied figures derived from elaborate and expensive "Creep" tests, under laboratory conditions, to the design of plastic assemblies by means of formulae applicable only to elastic materials in normal temperature structures. In many cases, too, careful, expensive determinations have been made on an improperly selected alloy of inferior utility for the service considered, or worst of all, the grade so tested may have one or more of its constituents on a highly sloping physical property curve in which case (as compared with the sample tested) slight variations in analysis (silicon and nickel particularly) produced in normal manufacture could easily halve or double the creep rates evidenced in succeeding lots of alloy.

There is a great need to simplify this field and remove some of the confusion that exists as between users and manufacturers and it is hoped that the following discussion will bring out some of the fundamental factors upon which proper selection and use of heat-resisting alloys should be based.

At the present time standardization must be of a somewhat general and limited nature and directed to rather broad composition classifications and grouped industrial uses and this may always be true because, even with detailed and exact data available as to alloys themselves, successful performance in service will still depend mostly upon the ingenuity of design and the extent to which allowances have been made for the effects of temperature fluctuations and inequalities and other phenomena not encountered in normal temperature engineering and operation. In all cases where exceedingly small performance tolerances are demanded it is advised that purchaser and manufacturer co-operate to insure perfection in analysis, design, production procedure and control of operation.

HEAT RESISTING ALLOY COMPONENTS

The term "heat-resistant" or "heat-resisting" has come to be accepted as designating alloys for use at temperatures where iron or steel or non-ferrous alloys fail due to oxidation or high-temperature corrosion and this includes the range from about 1200 degrees Fahrenheit to the highest temperatures at which any allow may be employed in air or the more common combustion gases.

A thorough search among all the alloy forming elements has condensed the commercial heat-resisting alloy list to those based on chromium with nickel and/or iron (see Fig. 2) and usually minor percentages of other elements. Certain intermetallic compounds—such as Cr.-Al.—have been found to resist oxidation up to 3000 degrees Fah., but as yet production has been limited to a laboratory scale.

In spite of this simple basis upon which all heat-resisting alloys are constructed the trade named offerings of many manufacturers and the variety of requests from numerous buyers have resulted in a market cluttered with a hundred or more proprietary alloy "grades" each made up of these three elements in different proportions whereas, with a view to simplification, all of these with reference to com-

* Written B.C. (Before the Code).

position and performance ability can be grouped into quite a short list of analyses.**

Such a list of "standardized" analyses has been evolved from researches, production, and field experience extending over a period of more than fifteen years and involving about every combination in an alloy that could be concocted with any promise of industrial "heat-resistant" qualifications.

In the earlier stages of development a great deal of cost and effort were expended in determining **relative** values among the maze of available analyses in order that only those having the most useful properties should be subjected to expensive final quantitative investigations with respect to high-temperature utility.

This procedure has made available a small number of alloys which by their especial fitness can logically eliminate a large number of other nearby grades having inferior properties.

A survey of the broad field of chromium alloys shows an area of property variations which may be likened to hills and valleys and with a number of particularly high points: and the grades selected for the Fahralloy series are the highest points of the entire area, each of which when viewed in the light of general industrial requirements seems to combine valuable properties to a higher degree than are available in any neighboring analysis.

The utility of an alloy for a given high-temperature service is usually measured by one or more of the following high-temperature characteristics:

Chemical

Surface stability or resistance to oxidation or attack by surrounding media.

Physical

- Strength or load carrying ability
- Stability against age hardening or phase change phenomena
- Specific Heat and Heat-content
- Heat transfer factors
- Electrical properties

(hot)

- Machinability
- Toughness

(cold)

To build these essential factors, even when known precisely, into equipment to operate satisfactorily under the many conditions of industrial high-temperature requirements is far more difficult than in structural or mechanical engineering of a similar nature at ordinary temperatures, and, in this field, design must be made with a complete understanding of all operating variables and requirements and with full allowance for many deteriorating influences not encountered at low temperatures. These commercially important characteristics of heat-resisting alloys will be considered in the order given above.

SURFACE STABILITY OF ALLOYS AT HIGH TEMPERATURES

A metal or alloy can be termed "heat-resisting", as regards surface stability, only with reference to some clearly defined set of requirements. Thus, tungsten is a very superior "heat-resisting" material in an atmosphere of nitrogen, argon, or in a vacuum, but tantalum, while of nearly as high melting point cannot be used in nitrogen, and neither of these is as heat-resisting as ordinary cast iron in open air. Platinum is very "heat-resisting" in open air, but in an atmosphere of CO gas or metallic vapors or in contact with certain salts it is unstable at quite low temperatures. Lead is more "heat-resisting" than nickel or iron when in contact with hot sulphuric acid, and iron is a better material than platinum for lead melting pots.

Such obvious examples illustrate the fact that insofar as resistance to high-temperature corrosion is concerned any given metal or alloy is "best" with reference only to some one set of conditions.

Resistance to oxidation or corrosion, however, is only one of several criteria which must be considered when selecting equipment for high-temperature operation. If this property alone were needed it would be relatively easy to meet very rigid requirements. The real difficulty lies in combining with some required surface stability the necessary physical and mechanical properties and then building all of these into a commercial unit of proper design.

Surface stability in metals and alloys at high temperature is due either to:

(1) Intrinsic inertness under conditions of exposure;

(2) The formation of an adherent, impervious protecting compound through non-progressive reaction between metal or alloy constituent and one or more corrosive agencies of its environment.

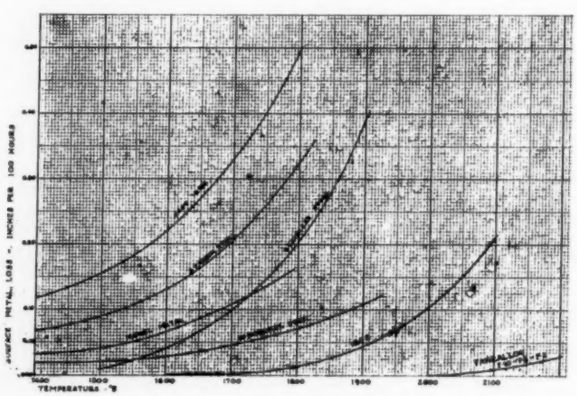


FIG. 1

Gold, silver, platinum and several other elements fall in the first class while industrial "heat-resisting" alloys are of type two.

The curves of Fig. 1 show some comparative oxidation rates secured in a certain testing of several materials heated in air at elevated temperatures. Such data are of limited value, however, as neither these curves nor the relationships among them would be the same for these same alloys if heated in products of combustion of a high-sulphur fuel, while different proportions of O_2, CO, CO_2, etc., in the heating atmosphere would likewise cause considerable shifting of these curves.

In the case of a high-sulphur fuel for instance, iron or nickel is rapidly attacked, whereas a high-chromium, nickel-free alloy is practically immune. Many processes require alloy units to serve at high

**These same comments apply to nickel-chromium alloys for the corrosion resisting field.

temperatures under reducing conditions or in contact with fused salts or corrosive gases of various kinds, and it is quite evident that **oxidation**-resisting alloys are not necessarily resistant to these other atmospheres. It is obvious, therefore, that diverse high-temperature surface stability cannot be found in a single all-purpose alloy.

A thorough search among all the alloy forming elements has uncovered none other than combinations of chromium with nickel or iron (or both) which have the necessary high-temperature surface stability under a wide range of industrial conditions.

Figure 2 shows this ternary field on which is indicated some of the compositions which have formed substantial portions of the thousands of tons of Fahralloy castings produced and sold since 1917 or which have been carefully investigated for commercial utility.

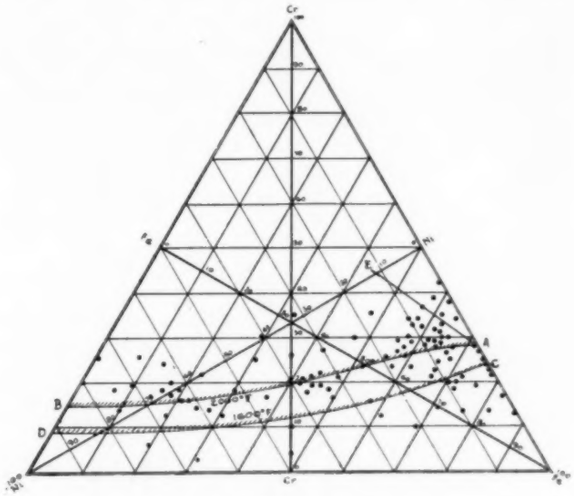


FIG. 2

On Figure 2—line AB indicates minimum chromium content required in alloys to give long life at 2000 degrees Fahrenheit and line C-D for 1600 degrees Fahrenheit under ordinary oxidizing conditions.

Line A-E indicates roughly the nickel-chromium requirements for 1850 degrees Fahrenheit resistance to gases of high-sulphur content, as in sulphide ore roasting operations.

It is quite out of order, however, to generalize too far with respect to surface stability of alloys at high temperature because a slight percentage of an additional unsuspected variable may completely upset behavior conclusions drawn from past performance in an apparently identical process. If any uncertainty exists, actual preliminary tests should be run under truly representative condition and from among the alloy grades which have satisfactory surface stability, that one should be chosen which combines the best combination of required physical characteristics consistent with cost.

Aside from oxidation only the possibility of sulphur corrosion or carburization need be considered in the usual fuel fired installations. That all these alloys **carburize** in a CO or hydro-carbon atmosphere at high temperatures is well known. Furnace conveyors of the popular 2812 alloy will readily go from a .30 carbon content as cast up to about 2.% after several months service, which, in certain cases is accompanied by volume changes sufficient to produce excessive warping. For alternating reducing and oxidizing service highly carburized alloys may become a bit low in oxidation resistance.

High sulphur fuels prohibit the use of high nickel furnace parts. 1865* and 1835* are suitable for natural gas or other fuels wherein sulphur is below 1.%. In combustion gases from coal containing up to 5% sulphur or raw producer gas from such fuels it is necessary to keep nickel below 12% and chromium above 28%. Even this alloy will not resist the sulphur concentration in sulphide ore roaster gases and such parts are ordinarily made of the 2802 type.

A given sulphur content in combustion gases seems to be more harmful when such gases are on the reducing side, as in most normalizer and pack furnaces.

SURFACE STABILITY VS. FOUNDRY PRACTICE

An often neglected factor of very great importance in determining the service life of castings is that of solidity, in terms of complete provision for decreasing volume in passing from liquid to solid.

All alloys in this series present quite a problem in this respect and unless sufficient reservoir or "head metal" is provided, castings will have solid exteriors with porous or spongy interiors.

Furthermore most of these alloys have quite a wide range between "liquidus" and "solidus" (i.e. completely liquid and completely solid) and the grain nuclei or first formed dendrite skeletons are nearly always higher in iron than the section average and all spongy, insufficiently "fed" areas, being filled with such chromium-deficient material, will eventually prematurely oxidize or "boil out", seemingly regardless of depth below the surface.

In a 2812 casting, for instance, such porous areas will run from 3 to 6% lower in chromium than the completely fed sections. These areas show up on fracture as dark spots which upon microscopic examination usually display a beautiful structure of "fern leafs" or interlacing needles.

PHYSICAL STRENGTH AT HIGH TEMPERATURES

After surface stability, the usual next question relates to physical strength of the alloy at the specified temperature. In fact, physical strength is commonly the governing factor in selecting an alloy for high-temperature service but has nearly always to be considered in combination with surface stability or some other characteristic.

High-temperature strength in heat-resisting alloys is primarily a function of composition and is herein considered first **relatively,** in the light of effects imparted by varying additions of each available alloying element, and then quantitatively in terms of creep stresses and safe working loads for certain analyses selected for outstanding utility. Before discussing either, however, the term "physical strength" should be defined because at high-temperature this is a property differing markedly in its practical aspects from "physical strength" as employed in structural design for bridges, buildings, or the like.

* 1865 means 18% chromium and 65% nickel and this manner of indicating chromium and nickel content is followed herein.

The relatively rapid decrease in physical strength of all metals with rising temperatures has long been known in general but this phenomenon is not yet sufficiently appreciated by many designers and users of high-temperature alloy equipment. It has not been fully appreciated either, that the time factor is predominant in fixing allowable stresses, nor that the calculation of stresses which will probably be encountered in service must include allowance for thermal expansion and contraction many times greater than in ordinary designs, and further, that the degree and distribution of these thermal stresses are quite dependent in turn upon such other properties as specific heat, thermal conductivity, radiation characteristics, and also upon design or operating conditions which affect transfer of heat or distribution of temperature.

The physical properties at high-temperatures of such metals as iron or nickel, or of the so-called "heat-resisting" alloys, will be better understood if one considers that with temperatures approaching the melting point these metals change progressively in general strength characteristics to resemble the more fusible metals, as copper, then aluminum and lead. An increase in temperature is usually accompanied by an increase in thermal expansion rates and in specific heat, while the ultimate and elastic strength and the modulus of elasticity all decrease, approaching corresponding values for the less refractory metals. Lead, tin and zinc at atmospheric temperatures have practically no elastic strength and neither has soft steel nor heat-resisting alloys at a corresponding range below the melting point.

In further comparison, lead or tin cannot be materially hardened by cold-working and, similarly, deformation in iron or nickel or steel or heat-resisting alloys at high-temperature will, if not too rapid, be continuous without causing work-hardening.

TIME VS. HIGH TEMPERATURE STRENGTH

When ordinary metals or alloys are broken under normal tension-testing procedure, i.e., pulled at the rate of around .05" per minute, their breaking strengths will decrease with increasing temperature as shown for iron and one grade of Fahralloy for comparison by curves A and B of Fig. 3. These values so obtained, however, are many times higher than their ability to carry loads at corresponding temperatures over **long periods** of time and **should never be employed** in the calculation of sections of high-temperature load-carrying members. Curves A and B for these same materials give tensile strengths when pulled at the rate of approximately 1% per 10,000 hours, and a comparison of these two sets of curves shows how the time factor becomes the deciding element in fixing permissible stress limits.

Experience with metals and alloys maintained under continuous stress for long periods of time at various temperatures furnishes strong argument against the existence of any true elastic limit at high temperatures and in favor of a continuous viscous flow, but whether or not metals show a continuous progressive deformation under stress is of little practical interest when it is known that for industrial application at a given temperature one may usefully employ a certain maximum stress below which the rate of deformation is **so low** as to be practically unmeasurable or, at least, not to exceed a permissible maximum throughout the service life of the metallic unit.

Regardless, therefore, whether metals and alloys at high temperatures do possess elasticity or whether they behave as plastic or viscous materials with a definite stress-flow value for each temperature, they do possess a practical load-carrying ability, which can be utilized in the operation of high-temperature mechanisms.

It may be stated then that the criterion of utility of an alloy high-temperature stress member is not any **static strength value** in the ordinary sense but rather a permissible overall **rate of deformation.**

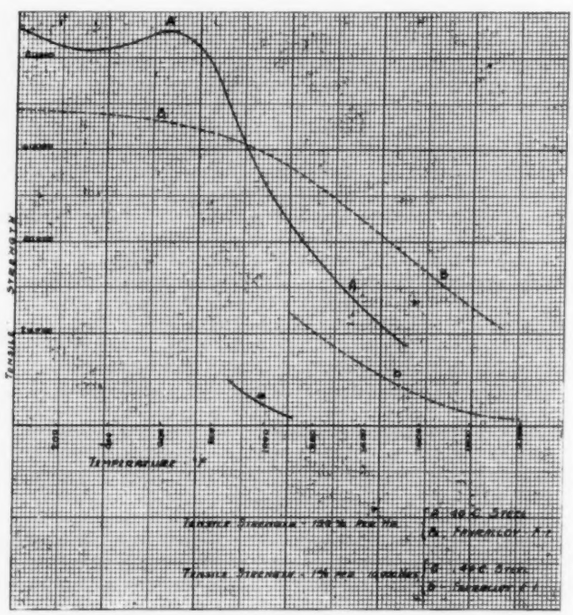


FIG. 3

Having shown under "surface stability" the range of analyses which possess industrial "heat-resistance" the logical next step is to consider the alloys within this available field (Fig. 2) as regards their relative order of deformation rates under comparable stress—time—temperature conditions, or in other words to compare the practical load-carrying ability of many possible alloys within this surface stability area in order to permit the selection of a few of superior utility.

HIGH TEMPERATURE STRENGTH VS. ANALYSIS

The application of a physical-strength yardstick to all alloys within the range of surface stability shows this area to be made up, figuratively, of hills and valleys—the highs and lows, in terms of relative high-temperature strength, being functions of analysis, with both major and minor constituents playing an important part. The effect of composition upon high-temperature strength has been recognized in a general way for some time but the development of the Fahralloy series has eliminated a great many possible compositions and has resulted in a few selected and proved analysis each having

some outstanding combination of surface stability, working strength, and other desirable qualities.

Commercial production in this series of alloys from 1917 to 1921 was chiefly of the chrome-iron type but requirements for greater high-temperature strength and toughness instigated investigations which resulted in the "1835" type of alloy which combines toughness—machineability, stability and high-temperature load carrying ability to a degree not exceeded by any other known composition.

Later insistent demands for the high-temperature strength of 1835 combined with increased sulphur-resistance brought out the Fahralloy F-10 or the 2812 type.

In like manner other special grades have been worked out to meet some particular set of industrial requirements and this long time series of investigations, coupled with the detailed study of hundreds of commercial installations, have evolved quite accurate knowledge of the relationships between analysis and high-temperature behavior.

In Figure 4 this general relationship between composition and high-temperature load-carrying ability is shown in a single picture in terms of deformation rates secured under conditions identical as to stress, time and temperature.

This list of alloys avoids any classification as to grades but covers the field of compositions found most useful to date. Complete analysis for each alloy is given, together with its deformation rate at 1600 degrees Fahrenheit and at 2000 degrees Fahrenheit when subjected to beam loads applied in a manner similar to that encountered in the average run of furnace operation.

This set of figures was derived from a series of horizontal beam tests * made to determine the relative order of magnitude of high-temperature strength in a series of analyses—and further to check records of relative field performance in a long list of commercial installations, and the values given are actual measured permanent deflection or sag.

The beam members for these tests were made from electric furnace heats, cast in sand molds in accordance with commercial casting practice. All bars were subjected to transverse loading under identical conditions of time and temperature and under an extreme fibre stress of 5000 P.S.I. at 1600 degrees Fahrenheit and 1400 P.S.I. at 2000 degrees Fahrenheit in accordance with the empirical transverse formula $F = \frac{M}{S}$ **

Wherein F = P.S.I. "Extreme Fibre Stress"
M = Bending Moment
S = Section Modulus

and in the light of this behavior it is difficult to justify current blanket recommendations of laboratory creep values for design purposes.

It is recognized that any deformation rate shown on Fig. 4 is greater than could be permitted in ordinary furnace installations as the duration of these tests was 30 hours only, but this behavior is exactly what would happen were furnace beams designed and used in a similar manner. The figures are **accurately relative** for the various analyses over quite a wide range in temperatures as these rate relationships have been checked and shown to hold closely throughout the range 1400 degrees Fahrenheit to 2000 degrees Fahrenheit, or, in general, above the work hardening temperature for these alloys. The effects of higher and lower stresses (***) applied to a wide variety of sizes and shapes of beams have also been determined and all these results combined with the observed behavior of many industrial installations would indicate that the relative order of deformation rates shown on Fig. 4 has properly classified the various analyses of heat-resisting alloys in terms of commercial load-carrying ability.

The sag values are also graphically shown as horizontal bars drawn to scale, the length of bars being proportional to the amount of sag under identical stress-temperature-time conditions. This facilitates comparison and gives a birdseye view of the whole group of relative strength figures. Inasmuch as time-temperature-stress is identical in all tests the values for total deflection may also represent relative **rates** of deformation.

(The supports for the beams were only 1.56" high, so a sag of that amount brought the middle of the bar to the furnace hearth level and all sag values so indicated would have been greater if supports had been higher).

The graphs of Fig. 4 show strikingly how certain small variations in analysis affect high-temperature strength, but conclusions which may be drawn will be more evident from a classification of these relationships wherein each element in turn is considered in the light of its imparted characteristics.

The high-temperature strength effects imparted by the major alloying elements chromium and nickel will first be shown and then the minor constituents carbon, silicon, manganese, aluminum, molybdenum, etc., considered in turn.

While there is, of course, a gradual merging of one classification into another these alloys may be roughly grouped as below for purposes of discussion:

1—Chromium-Iron plus minor constituents
2—Chromium-Nickel plus minor constituents
3—Chromium-Nickel-Iron Ternary Series
- A Cr. 25-30%
  Ni. 5-15%
  Balance mostly iron
- B Cr. 15-21%
  Ni. 30-40%
  Balance mostly iron
- C Cr. 13-21%
  Ni. 50-65%
  Balance mostly iron

Each of these broad groups has been thoroughly studied and those compositions of superior general utility designated as standard grades of Fahralloy. Each grade, of course, to be varied within narrow limits to suit conditions.

(Iron-Chromium Series) Fahralloy F-3 (2803)

See alloys 10, 11, 15, 16, 17, 18, 19, 20, 21, 39, 40, 41, 42 on Fig. 4.

The addition of chromium to low carbon or me-

* In many hundreds of tests for relative high-temperature strength many types and sizes of beams have been used, but in the list selected for Fig. 4 all test bars were .25" thick (high) by 1" wide and carried on a 9" span with center load.

** For a criticism of the use of this formula in high-temperature alloy design see Page 197.

*** For discussion of the effect of load variation upon rate of deformation see Page 198. See page 199 also for data as to relative rates of deformation in tension vs. compression.

		ANALYSIS						BEAM TEST AT 1600°F RELATIVE DEFLECTION			BEAM TEST AT 2000°F RELATIVE DEFLECTION			
		C	Mn	Si	Cr	Ni		INCHES		GRAPHIC SCALE	INCHES		GRAPHIC SCALE	
1		.43	.93	.24	18.06	37.47		.020			.250			1
2		.65	.25	.35	18.92	35.76	SAME HEAT	.040			.220			2
3	Si			1.47			SAME HEAT	.060	Si		.280	Si		3
4				2.91			SAME HEAT	.140			.370			4
5		.83	.12	.47	17.63	36.80		.070			.370			5
6		.35	.77	1.48	23.33	12.73		.040			.590			6
7	W	.40	.77	1.27	23.41	11.65	W 4.76	.040	W		.590	W		7
8		.33	1.44	1.07	25.36	9.34	W 2.94	.040			.540			8
9		.38	1.54	.88	22.75	6.00		.170			1.090			9
10		.32	1.27	.22	28.38			1.560			1.560			10
11		.45	.27	.30	31.56	0.00	SAME HEAT	1.330			1.560			11
12	Ni					2.90	SAME HEAT	.650	Ni		1.560	Ni		12
13						6.06	SAME HEAT	.220			.680			13
14						10.16	SAME HEAT	.080			.340			14
15		.83	.28	.33	25.09		SAME HEAT	1.150			1.560			15
16	Si			1.60			SAME HEAT	1.330	Si		1.560	Si		16
17				3.10			SAME HEAT	1.560			1.560			17
18		.75	.37	.52	26.30		SAME HEAT	.750			1.560			18
19	Mn		1.37				SAME HEAT	.920	Mn		1.560	Mn		19
20			3.16				SAME HEAT	1.110			1.560			20
21		2.15	1.15	.82	37.45			.750			1.560			21
22		.35	1.07	1.44	10.54	21.09		.230			.570			22
23		.37	.80	2.19	18.05	63.80		.160			.460			23
24		.79	1.31	1.34	15.86	62.85		.110			.320			24
25		.75	1.25	2.64	14.67	61.95		.180			.450			25
26		.79	.26	.42	13.31	58.24	SAME HEAT	.060			.280			26
27	Si			1.60			SAME HEAT	.110	Si		.310	Si		27
28				3.20			SAME HEAT	.130			.470			28
29		.33	1.29	1.04	26.12	15.27		.070			.410			29
30		.35	1.26	.61	26.99	15.32	SAME HEAT	.100			.320			30
31	Ni					19.55	SAME HEAT	.080	Ni		.240	Ni		31
32						23.82	SAME HEAT	.060			.240			32
33		.54	1.24	.77	26.51	14.93		.050			.340			33
34		.12	.44	.18	20.03	9.18		.070			.710			34
35		.14	.45	.23	19.74	9.43		.100			.630			35
36		.20	.36	.19	19.44	9.37		.120			.710			36
37		1.10	.93	.43	22.35	11.30	Al 1.0	.078			.600			37
38		.37	.82	.75	20.39	9.80		.100			1.150			38
39		.50	1.86	.89	22.49			1.560			1.560			39
40		1.15	1.65	1.02	21.99			1.560			1.560			40
41		1.22	1.62	.68	22.49			.630			1.560			41
42		1.54	1.25	2.43	22.88			1.560			1.560			42
43		.14	.25	.45	29.82	7.82	SAME HEAT	.100			.590			43
44	Car	.56					SAME HEAT	.070	Car		.340	Car		44
45		.76					SAME HEAT	.100			.340			45
46		.45	1.38	.36	27.85	9.24		.100			.410			46
47		.47	.27	.75	28.81	7.40	SAME HEAT	.080			.220			47
48	Mn		1.37				SAME HEAT	.085	Mn		.220	Mn		48
49			3.29				SAME HEAT	.100			.250			49
50		.55	.25	.25	31.56	6.06		.220			.680			50
51		.55	.25	.30	28.48	10.16		.080			.340			51
52		.56	.25	.45	29.82	7.82		.070			.340			52
53		1.92	.98	1.85	33.30	10.67		.150			.610			53
54		.86	3.27	.35	29.42	5.89		.100			.310			54
55		.85	4.25	.35	29.42	5.89		.100			.310			55
56		.83	4.73	.33	27.76	7.11		.090			.340			56
57		.83	.23	.38	29.24	8.13	SAME HEAT	.115			.340			57
58	Si			1.75			SAME HEAT	.115	Si		.530	Si		58
59				3.14			SAME HEAT	.230			1.560			59
60		1.20	1.49	1.05	28.30	8.86		.070			.563			60
61		.37	.11	.56	14.24	49.07	Mo 19.35	.150			.270			61
62		.43	1.10	.73	11.62	46.22	Mo 20.00	.150			.220			62
63		.99		.63	15.03	47.00	Mo 15.36	.070			.270			63

FIG. 4

dium carbon steel increases its high-temperature strength considerably but these Fe-Cr. binary alloys have the lowest strength of any within the range possessed of high surface stability and are used as structural members only where compelled by requirements of corrosion resistance at operating temperatures, as for instance in contact with gases sufficiently high in sulphur to preclude substantial nickel content. Note the relatively high rate of deformation of 10 or 11 or 15 for instance as compared to No. 1 and others containing nickel. Where permitted or required by operating conditions, nickel, carbon, etc., may be increased to improve high-temperature strength, wear resistance, or the like. A range in this series containing Cr. 27-30,—nickel 0-3% is designated F-3. This grade normally contains around .30-.50 carbon, under 1% manganese and silicon.

All alloys of this series are quite brittle as cast, or become so due to "age-hardening" upon prolonged heating. These alloys are quite readily machinable when of proper carbon-chromium ratio. This F-3 grade was first offered by the writer in 1918 and in various modifications has developed world wide use in arms, rabble blades, etc., for ore roasting equipment. It might be remarked in passing that commercial utility of this series does not depend alone upon surface stability or high-temperature strength but finds wide use where hardness and wear resistance is also required.

(Chromium-Nickel Binary Series)

Except for very special cases this class is not required in cast form, and serves at high-temperatures chiefly as resistor heating elements in rolled wire or ribbon form. These alloys, represented by the 80 nickel 20 chromium type, are much stronger than the chromium-iron binary series but have a higher deformation rate than some of the alloys containing chromium—with both nickel and iron. Because of high-priced raw materials, castings of this class have not found extensive commercial use.

(Chromium (20-30%) Nickel (5-15%) plus Iron)

Additions of nickel to the chromium-iron base increase high-temperature (strength, at first very rapidly and then, with lessening effect, until, **on a strength basis alone,** a maximum benefit is reached at about 10%, beyond which the increased strength is not worth the extra cost of more nickel. Where operating requirements will permit the use of higher carbon content—say .75 to 1.15%, maximum strength can then be secured at around 7.% nickel.

Reading from Fig. 4 the chromium-iron alloys containing 20 to 30% chromium are shown to be affected by progressive nickel additions with respect to increased strength, as follows:

Alloy No.	Ni. %	Sag of bar at 1600° F.	Sag of bar at 2000° F.
11	0.0	1.33"	1.56 plus
12	2.9	.65	1.56 plus
13	6.06	.22	.68
14	10.16	.08	.34
30	15.32	.10	.32
31	19.55	.08	.24
32	23.82	.06	.24

Note the striking effect of the first small percentages of nickel in reducing the relative amount or rate of sag. In view of the fact that the cross sections (and weights and costs) of members in high-temperature mechanisms are usually designed with respect to some predeterminated maximum distortion limit, the need for proper nickel content is quite obvious.

Factors other than strength, however, may set limits for nickel—as, for instance, stability in high-sulphur furnace gases, which requires low nickel content with unavoidable sacrifice of strength. On the other hand, requirements for greater stability against age hardening, greater ductility, or the like, may dictate even higher nickel, with slight attending strength increases and at considerably greater cost. There is practically no gain in high-temperature strength above 10% nickel but a very rapid loss,—and also a serious increase in brittleness and age hardening below 10% so in this class of alloy the limits for best all around results should be set at about 11% to 13% nickel. Applying only the two criteria of surface stability and high-temperature strength it is apparent that chromium should be above 27% and nickel above 10% for maximum utility at temperatures up to 2000 degrees Fahrenheit.

One grade of Fahralloy F-10 (2812) contains 11-13 nickel, 27-30% chromium with silicon, manganese and carbon as required. (See later pages relating to effects of these minor constituents). The utility of this F-10 grade has been proved by the performance of many hundred tons of castings in service for the past six years.

One might list a number of "grades" close to the analysis of this 2812, but for normal uses nothing would be gained, and common agreement on such a standard would simplify selection for the purchaser and avoid production multiplicity for the manufacturer. Furthermore, the checking of competitive offerings within standard analysis limits would permit a direct comparison of quality and price not easy otherwise.

Chromium (15-21)—Nickel (30-40) plus Iron

Figure 4 shows that with chromium above 25% —strength is not appreciably increased by adding more than 12% nickel. If, however, chromium content is dropped to around 16-20% somewhat greater strength is attained with higher nickel (between 30% and 40%) and other valuable characteristics are added at the same time. Compared to lower nickel and higher chromium castings this type of alloy is more stable as regards allotropic changes, is softer and more ductile as cast and when of low carbon is quite free from embrittlement due to carbide-precipitation or other forms of age hardening in service.

The maximum high-temperature strength is secured at around 33% nickel but is nearly the same between 30 to 40%. Low chromium (around 13-15%) gives greater toughness and ductility but 18-21% is required for surface stability at high-temperatures. High strength requires also low silicon and carbon as illustrated on Fig. 4.

This grade is designated Fahralloy F-1 (1835) and was produced commercially first in this series in 1921 and has since come to be an accepted standard grade offered under different trade names by

various manufacturers. It is superior to all other grades as an all-around high-temperature structural member—but has the one objectionable feature of low resistance to high-sulphur gases.

Alloys Nos. 1, 2, 3, 4 on Fig. 4 show typical properties for this standard F-1 grade.

Chromium (12-21)—Nickel (50-65) plus Iron

Further increasing the nickel to above 40% tends to somewhat reduce the high-temperature strength regardless of other components but nearly all manufacturers furnish grades containing around 50-65% nickel and from 12-21% chromium; some analyses of which have proved of exceptionable merit for carburizing containers, retorts and the like, and for contact with certain fused salts and slags which tend to form chromates with the protective oxide coating of the high chromium, low nickel alloys. This grade of alloy also is superior where repeated and drastic temperature fluctuations and gradients are encountered and where a high degree of phase stability and freedom from age hardening is required.

Fahralloy F-5-A is a standard grade containing 60-65% nickel and 18-21% chromium. F-5-B runs 50-60 nickel and 13-15 chromium and is made to meet certain limited demands.

These four classes viz: F-3, F-10, F-1 and F-5 ranging in order from no nickel to 65% nickel and with properly adjusted minor constituents present to a high degree the best combination of physical strength and surface stability at the very highest working temperatures.

Chromium (16-25)—Nickel (5-10) plus Iron

For intermediate temperature ranges (below 1800 degrees Fahrenheit) alloys with somewhat lower chromium and nickel content will possess sufficient surface stability, and nickel, carbon and silicon can be adjusted to meet physical strength or casting requirements.

The Fahralloy series offers several general grades of heat-resisting castings including the popular, but often over-rated "1808" (F-8). Fahralloy F-2 (2205) combines higher scaling resistance than 1808 together with toughness, machineability and considerable strength at intermediate temperature ranges and finds considerable application for requirements up to 1650 degrees Fahrenheit. The 1808 alloy begins scaling at 1600 degrees Fahrenheit and has fair strength at that temperature, but it is quite unstable as to critical points—showing objectionable sudden changes in expansion or contraction and the like upon heating or cooling.

Fahralloy F-2-B finds considerable demand for temperatures below 1800 degrees Fahrenheit and is quite satisfactory where temperature changes are slow and infrequent, in spite of its high carbon content. It is of about the same strength as F-10 up to 1800 degrees Fahrenheit but will scale at higher temperatures. See No. 37 on chart 4.

Where machineability and toughness can be sacrificed, relatively less costly alloys can be used with low nickel, or no nickel, and higher carbon content. For temperatures just above those permissible for ordinary steel or iron—a chrome cast iron or low chrome steel can be used to advantage—this in the range around 1100-1400 degrees Fahrenheit.

For uses which do not require maximum strength but demand the maximum of surface stability at high temperatures Fahralloy F-35 (alloy 21 and 53) is available. This series varies from 0-15% nickel and 32-40% chromium and finds use in specialty processes requiring high surface stability, wear resistance, machineability and thin intricate castings. Several special F grades also are available having surface stability combined with high resistance to wear and the like, but are not to be classed strictly as heat-resisting alloys.

Having considered the influence and indicated the desirable percentages of the major constituents it is next in order to outline in general the part played by each of the minor constituents which are either unavoidably or intentionally present in heat resisting alloys.

EFFECT OF CARBON

In general, the influence of increasing carbon content is to lower high temperature strength in high nickel or austenitic alloys and to raise it in the high-chromium or ferritic classes.

In planning to utilize for load carrying purposes the strength imparting effects of high carbon in the high chromium (20-30%) low nickel (0-12%) alloys one important fact should not be overlooked. The solubility of carbon or carbides in the alloy changes with the temperature and for this reason carbon-induced strength is not nearly so dependable in operations where the alloy is subjected to heating and cooling cycles as it may be in installations where the alloy is maintained at one definite temperature. This fact has been lost sight of in many tests to determine creep limits on high carbon chromium alloys.

Some observed effects of carbon in the Fahralloy grades are as follows:

Effect of Carbon in Fahralloy F-1 (1835)

Decreasing the carbon (down to 0.15 % tested) increases high temperature strength—low temperature toughness and ductility,—stability under fluctuating temperatures, and cost and difficulty of casting.

Higher carbon content increases fluidity and ease of casting, lowers the cost of raw material, and to some slight extent lowers resistance to oxidation. It has been claimed that increasing carbon content will proportionately decrease resistance to oxidation at high temperature, but this is not true, for the reason probably that at high temperature the solubility for carbon or carbides is increased and a solid solution alloy exists; even perhaps with more than 1% carbon in some grades. (In the case of liquid corrosion at low temperature, carbide formation, of course, markedly effects corrosion resistance.)

The effect of carbon on the high temperature strength of Fahralloy F-1 grade is shown by alloys Nos. 1, 2 and 5 from Figure 4, as follows:

No.	C %	Rate of Sag 1600°F.	2000 ° F.
1	.43	.020	.25
2	.65	.040	.26
5	.83	.070	.37

Commercial castings high in nickel run from

around .25 to 1.25% carbon and it is evident from the above tabulation that in the high nickel grades the lower cost of high carbon alloys may be more than offset by the higher section modulus and accompanying greater weight required for a given load-carrying service.

The same effect holds true in the higher nickel (1865) alloys (Fahralloy F-5) but seemingly to a lesser degree and these are seldom used for strength alone anyway, so the greater ease of producing the intricate castings usually called for in this grade by the use of a higher carbon content is considered in most cases an all around advantage, and the cost is lower.

Effect of Carbon in Fahralloy F-3 (Chromium 27-30) (Nickel 0-3)

In the chrome-iron alloys the high temperature strength increases with carbon content (up to about 1.25% C) but so also does hardness and brittleness at room temperature and likewise embrittlement due to age hardening.

In parts to be machined the strengthening effect of high carbon cannot be utilized because of accompanying hardness and excessive brittleness.

The following tabulation from Figure 4 shows the effect of carbon on the strength of F-3, which is of relatively low high-temperature strength regardless of carbon content, when the nickel is low.

Alloy No.	C.	Sag at 1600° F.	Sag at 2000° F.
10	.32	1.56 plus	1.56 plus
11	.45	1.53	1.56 "
15	.63	1.15	1.56 "
18	.75	.75	1.56 "
21	2.00	.75	1.56 "

Higher carbon percentage does not reduce resistance to oxidation to the degree indicated by theory nor to the extent observed in the case of wet corrosion at room temperatures. This is probably due to the fact that much of the carbon is held in solution at high temperature.

Effect of Carbon in F-10—F-8—F-2-B

In the intermediate ranges such as 18-08 or 2209 carbon increase is accompanied by some increase in ability to sustain loads above red heats, but increased carbon content, also greatly enhances carbide precipitation and age hardening and besides, if high enough, renders the alloy non-machineable as cast. Toughness and ductility as cast are rapidly decreased with carbon increase, but when carbon is under .15 in the 1808 and under .25 in 2812, these grades are extremely tough as cast.

The question of carbon content is also of considerable economic importance as regards raw materials and selling price, as castings of high carbon content can be made at lower cost. The matter of carbon content should be considered carefully, particularly, in heat treating furnaces, as a reducing atmosphere high in CO or hydrocarbons will carburize all heat-resisting alloys, especially those of the Cr.-Fe. series or the ternary alloys high in Chromium and low in Nickel. Normalizing conveyors of the 2812 alloy, for instance, have shown an increase in C./% from .30% up to 1.95% in less than a year. This accumulated high carbon content in such used castings adversely effects scrap values as such materials cannot cheaply be remelted to produce low carbon castings.

EFFECT OF MANGANESE

Manganese is usually employed as a scavenger or deoxidizer and is almost invariably present in these alloys in at least normal steel percentages. Its effect on high temperature strength, unexpectedly, is opposite from that of nickel but to a minor degree and manganese up to several percent may be present in any of these alloys without a serious weakening effect, or any substantial decrease in surface stability. High managanese, however, decreased machineability to some extent and increases the tendency to age harden in the high chromium low nickel alloys, and particularly in the chromium-irons. Alloys Nos. 18, 19, 20 and 47—48—49 show some effects of manganese variation.

EFFECT OF SILICON

This element is the foundryman's friend and every casting will be loaded with it up to several percent if not specified otherwise. Also, in acid melting, high silicon is difficult to avoid. Insofar as high-temperature strength is concerned Silicon is poison and can do more to halve the purchaser's dollar as regards service strength than any other factor.

Figure 4 shows how the rate of sag of alloy beams increases rapidly with silicon additions regardless of the analysis but this effect is least marked in the high-nickel, low-chromium alloys, and most striking in the chrome-iron series, but is also very marked in the 2812 and 1808 type.

The influence of silicon content on high temperature strength of the various types of compositions is shown in the following taken from Figure 4.

Alloy No.	Silicon	Sag at 1600° F.	2000° F
		F-5 TYPE	
26	.42	.060	.28
27	1.60	.11	.31
28	3.20	.130	.47
		F-1 TYPE	
2	.35	.040	.22
3	1.47	.060	.28
4	2.91	.140	.370
		F-10 TYPE	
57	.38	.115	.34
58	1.75	.115	.53
59	3.14	.230	1.56
		F-3 TYPE	
15	.35	1.15	
16	1.60	1.33	Quite plastic
17	3.10	1.56 plus	at 2000°F.

Hardness and difficulty of machining increases generally with rising silicon content as does also the tendency to age harden in service.

It does improve casting conditions by increasing fluidity and aids greatly in preventing cold-shuts and seams which are caused by the leathery chromium oxide coating which forms on the molten metal while flowing into the mold—but its harmful effects, insofar as high temperature strength is concerned, more

than offset a better appearance on the surface of a casting.

EFFECTS OF ALUMINUM

Aluminum is a very strong deoxidizer and permits the use of a high proportion of alloy scrap in the melting charge. A small percentage of aluminum in Heat Resisting castings will increase resistance to oxidation but lowers the high temperature strength when present in amounts much over 1.%. Castings containing over 1% aluminum are difficult to cast cleanly because of the aluminum oxide film which forms. In producing castings containing up to 15% aluminum it was found that great resistance to oxidation could be secured but with a substantial loss of load-carrying ability. Fahralloy F-2-B is a standard grade having considerable demand for use up to 1800 degrees Fahrenheit—and is very satisfactory where temperature changes are slow and infrequent. See No. 33 on Figure 4.

Effect of Tungsten and Molybdenum

From time to time the virtue of various additions of these elements has been extolled but, a rather thorough investigation has not shown a substantial increase in strength to be derived from their use. Amounts up to 20% of each have been used and the only striking feature observed was the greatly increased tendency to age harden. A slight strength increase in some cases resulted but on the whole these elements have not been found to improve these alloys at anything like commensurate cost.

Alloys Nos. 6-7-8 and 61-62-63 relate to these elements.

Other additions, such as copper, vanadium and titanium have been tried but none has been found to add substantially to the high temperature strength of the ni. cr. fe. class of alloys.

Selected Compositions of High General Utility

The graphs of Figure 4 clearly show which are the high strength analyses but to select a few alloys of superior **general** utility from among a large number which possess satisfactory high temperature strength is not easy and requires careful elimination with reference to casting qualities—machineability—surface stability—phase stability, first cost, unit service cost and many other considerations pertinent to particularized usage. Such an elimination contest can be successfully carried out only over a period of many years. After passing numerous alloy analyses through a grading screen made up of these various criteria there have emerged a few compositions possessing combined valuable properties to a higher degree than any others available at the present stage of alloy development and these high duty analyses constitute the several present grades of Fahralloy. For operation under most drastic conditions, requirements of general industrial use are fulfilled to the highest degree by the following major alloys:

	Carbon	Silicon	Manganese	Chromium	Nickel
F-1 —1835	.30—.50	1.25 Max.	.25—.75	18—21	33—38
F-3 —2802	.35—.60	"	.50—2%	27—30	0—3
F-5 —1865	.40—.80	"	.50—1.50	18—21	60—68
F-10—2812	.25—.50	"	.50—1.0	27—30	11—13

For operation under less drastic conditions, alloys of the following list are in sufficient demand to justify inclusion as standard grades.

	Carbon	Silicon	Manga.	Chrom.	Nickel	
F-2 2205	.30— .50	1.25 Max.	.30— .50	22—25	5— 7	
F-2-B —2209	1.00—1.25	"	.30— .50	21—23	7— 9	Al. 1.%
F-8 —1808	.10— .15	"	.35— .50	18—20	8—10	
F-10H—2812	.60—1.00	"	.50—1.0	27—30	8—13	
F-5-B —1560	.40— .80	"	.50—1.50	13—18	50—60	

First column, in Fig. 7, gives recommended $\frac{M}{S}$ values.

A = Stress for creep rate of 0.01% per 1000 hours.
B = Stress for creep rate of 0.1% per 1000 hours.
C = Stress for creep rate of 1.0% per 1000 hours.

These A—B and C values, in Fig. 7, are about average for the listed grades as slight variations in analysis will affect the creep rate. Furthermore these figures represent the maximum and demand ideal conditions, to be encountered only in the laboratory.

Recommended $\frac{M}{S}$ Values for Fahralloy Castings

°F	Carbon .10% C	Steel .40% C	0.1 % C 14.00% Cr.	F-2 2502	F-3 2802	F-8 1808	F-10 2812 Cast	F-1 1835 Cast	F-5 1865 Cast
1000	2000	4000	4500	6000	5000	9000	9000	12500	14000
1100	1000	2000	2200	4000	3000	6500	7500	10000	7000
1200			1000	2600	1500	4500	6200	8000	4500
1300			450	1500	750	3000	4800	6200	3200
1400			200	750	500	2000	3600	4500	2000
1500				500	300	1200	2500	3100	1500
1600				300	150		1400	2000	800
1700				150	100		700	1200	500
1800					50		400	600	300
1900							200	300	150
2000							100	150	75
2100								75	

FIG. TABLE 5

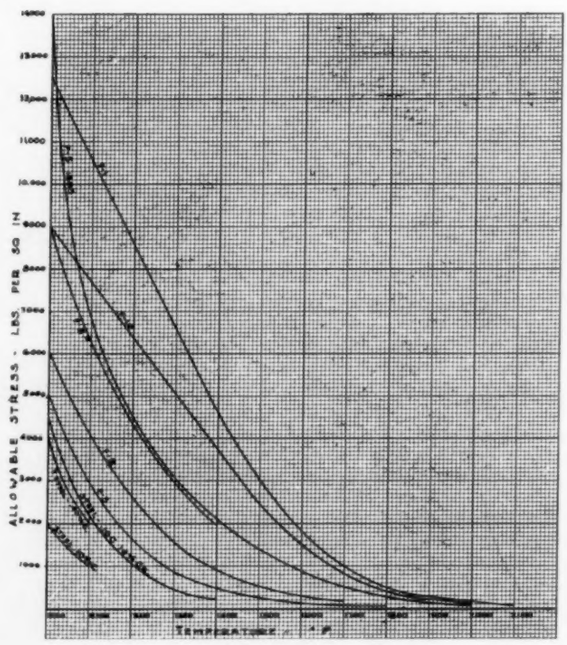


FIG. 6

	Fahralloy F-10		Fahralloy F-1		Fahralloy F-3		Fahralloy F-2-B	
Temperature degree Fah.	M/S	Creep Stress	M/S	Creep Stress	M/S	Creep Stress	M/S	Creep Stress
1000	9000		12500					
1100	7500		10000					
1200	6200		8000					
1300	4800		6200					
1400	3600	7200 A 9000 B 10800 C	4500	9000 A 11250 B 13500 C	500	1000 A 1250 B 1500 C	3600	7200 A 9000 B 10800 C
1500	2500	5000 A 6250 B 8750 C	3100	6200 A 7750 B 10850 C	300	600 A 750 B 1050 C	2500	5000 A 6250 B 8750 C
1600	1400	3500 A 4200 B 5600 C	2000	5000 A 6000 B 8000 C	150	375 A 450 B 600 C	1400	3500 A 4200 B 5600 C
1700	700	1750 A 2450 B 3500 C	1200	3000 A 4200 B 6000 C	100	250 A 350 B 500 C	700	1750 A 2450 B 3500 C
1800	400	1120 A 1600 B 2400 C	600	1680 A 2400 B 3600 C	50	140 A 200 B 300 C	Scales	
1900	200	700 A 1100 B 1600 C	300	750 A 1650 B 2400 C				
2000	100	400 A 700 B 1000 C	150	600 A 1050 B 1500 C				

FIGURE 7

Thus far, all discussion of the high-temperature strength of heat-resisting alloys has dealt with this property only in respect to its relative order of magnitude among various available analyses, without commitments as to actual load-carrying ability.

Figure 4, of course, shows that any alloy listed thereon when subjected to an extreme-fibre stress (under beam loads and in accordance with the formula $F = \frac{M}{S}$) of more than 500 P.S.I at 1600° Fahrenheit and 1400 P.S.I. at 2000° Fahrenheit will show a rate of deformation far too high for ordinary furnace construction.

A great many laboratory tests and a careful study of the performance of thousands of tons of alloy structural members in commercial installations have evolved a set of $\frac{M}{S}$ and creep rate values which form the basis of design of Fahralloy high-temperature equipment. The $\frac{M}{S}$ values are considerably lower than many currently advertised "safe load" values but the satisfactory performance of transverse structures so calculated would seem to justify considerable care in attempts to use higher stresses. These are given on the Table Fig. 5 and on Curves of Fig. 6 and may be used in the design of beam-type, high-temperature structural members in which the cross section is relatively small as compared to length—as in rails, plates and the like.

Figure 7 lists some creep values for several grades

of Fahralloy—and the corresponding $\frac{M}{S}$ values from Fig. 5 are included for comparison.

Except for operation under ideal conditions "creep" stresses dare not be used to full value and the usual assumption of precision in advertising such deformation rates for design use seems to the writer very much out of place under the average run of industrial conditions. Commercial variations in the mill run of alloy analyses: thermal expansion effects of unavoidable uneven heating and cooling, or temperature gradients; solubility changes accompanying fluctuating temperatures; and other variables encountered in usual commercial materials and operations are such important counteracting influences as to justify a substantial discounting of laboratory creep values and make it seem more logical to employ figures which have successfully served in a multitude of field installations. Another reason for this attitude lies in the fact that nearly all high-temperature structural units function as beams of one type or another under transverse loading, while nearly all creep data have been derived from straight tension tests and my work has shown that the relationship existing between tensile and transverse loading stresses of elastic materials does not hold for plastic materials. (See below.) This fact, to the best of my knowledge, has not been recognized in the design of alloy beams or transverse load carrying members and even the excellent work of Nadai* does not furnish means for utilizing tensile figures in transverse formulae for plastics nor mention precautions or factors to be used in converting elastic formulae to use with plastic alloys.

In addition to the above there are several other factors involved which must be considered by the engineer in deciding upon safe stress values or in judging what percentage of indicated "creep" values may safely be employed under a given set of operating conditions. Several of these which are peculiar to high temperature conditions alone, and ordinarily not assigned full weight in balancing a design, are discussed briefly in the following paragraphs.

EFFECT OF LOAD UPON RATE OF DEFORMATION

The rate of deformation in alloys at high temperature is not directly proportional to the load. The rate increases disproportionately with higher stress values.

The Curve of Figure (8) is plotted from tests in which beams of identical analysis and design were subjected to a series of increasing loads at 2000 degrees Fahrenheit—the duration of stress being the same throughout.

SPECIAL HIGH TEMPERATURE STRENGTH CONSIDERATIONS

Tensile vs. Transverse Loading

In applying the conventional transverse formula

$$\left(\text{extreme fibre stress} = F = \frac{\text{Bending Moment}}{\text{Section Modulus}} = \frac{M}{S}\right)$$

to the calculation of alloy beam sections it should be remembered that this formula was originally empirically derived to determine stresses in beams of elastic materials—structural steel in particular; and has served as a means for conveniently and safely applying to the design of beam structures, certain strength values which had first been determined in tests under straight tension.

It would not otherwise be permissible to use this formula in the calculation of sections of structural members of non-elastic materials, except that in the case of Fahralloy the "design" values tabulated were actually derived by the use of this formula from the

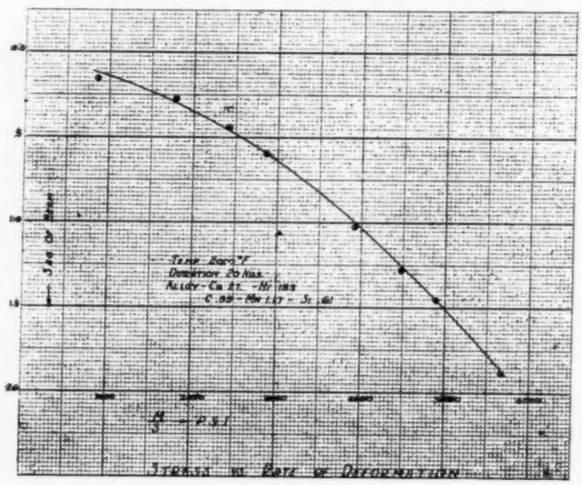


FIG. 8.

behavior of loaded beams and not from tension members, so all Fahralloy $\frac{M}{S}$ values, therefore, can safely be used to calculate beam behavior with no chance of error.

It should be recognized that stress distribution in a beam which is in the process of actual plastic deformation (as all beams herein considered are, regardless of rate of creep) is quite different from that in an elastic beam loaded well within its proportional limit but there is not yet sufficient data available concerning the behavior of alloy structural members at high temperatures under both transverse and tensile loads to enable proper correlation between the two sets of values, and the steel designers practice of substituting tensile functions in the transverse formula for the calculation of high temperature alloy beams, is not correct.

The cross-sectional increments of a beam are deformed at a rate directly proportional to the distance from the neutral axis and under a force leverage inversely proportional to this distance so that stress and strain distribution in any given cross-section is complicated by the rate-strength factor (see page 190) and also by the non-proportionality between load variation and rate of deformation.

We have been working on this problem for some time, by loading transverse and tensile members to identical formula stresses, with a view to working out a factor by means of which tensile creep data can be utilized in the conventional or other suitable beam formula. As it is, deformation rates deter-

*—Plasticity—Eng. Socy. Monographs.

mined either way cannot be stated in terms of the other.

It is seemingly evident from this that round or similar bars are the worst section for beam members and next in line are squares, flats or plates. The best beam section to use on a given job is the one which has its centers of area under both compression and tension at the farthest possible distance from the neutral axis, first—because of the more nearly straight, even, tension or compression throughout the respective area; second—because of the improved section modulus and, third—because with any given creep rate (or fibre deformation) the rate of sag of the beam as a whole becomes lower as the deforming stressed area is moved away from the neutral axis and this advantage is considerably more than proportional.

In view of these factors a skeletonized truss type of cast beam should be used whenever possible.

DEFORMATION IN TENSION VS. COMPRESSION IN BEAMS

Long field experience and many laboratory tests with alloy beams of symmetrical cross section (rectangles, I-beams, etc.) under load have shown that measurable bend is accompanied by shortening on the compression side exactly equaled to stretch on the tension side, the neutral axis remaining unchanged.

This is true of course only up to where bend is insufficient to substantially increase the compressed area or decrease the tension area.

This means that "creep" values for a given alloy will be practically the same in tension and compression.

In view of the disproportionate relationship between stress and creep rate as shown on Figure 8 it is recommended that compression and tension areas be equal and symmetrical with respect to the neutral axis—or of such distribution as to allow for the several variables described, otherwise one or the other will assume a disproportionate share of the overall deformation.

CAST VS. WROUGHT ALLOYS

Given an identical analysis, cast forms are generally somewhat stronger than wrought and in the high nickel alloys, such as resistor heating grades the difference is very marked, particularly when overloaded. The F-10 types show more nearly equal strengths in the wrought and cast forms. These are illustrated in the following tabulation of laboratory tests. Stress was dead load tension.

Alloy	Test Bar	Load P.S.T.	Duration	Total Stretch in 6"	Remarks
F-5 Cast	I-Beam	5000	115.	.012"	I-Beam Section 1"x¾"x⅛" thick
Rolled 2080	3/8" round	5000	22.	1-3/16" in 2" broke	Commercial Resistor Element
Rolled 2080	.22" square	4000	10.	⅝" in 2" broke	Commercial Resistor Element
F-1 Cast	I-Beam	4000	120 hours	Zero	I-Beam Section 1"x¾"x⅛" thick
F-10 Cast	3/8" square	5000	100 hours	.010	
Rolled 2512	3/8" round	5000	70.	.015	

STRENGTH VS. FOUNDRY PRACTICE

Due to high solidification volume shrinkage it is difficult to thoroughly "feed" alloy castings, with consequent danger of internal porous sections, and any internal unsound areas act as internal notches which eventually work to the surface through fatigue upon repeated heating and cooling.

Because of rather high pattern shrinkage coupled with a long "mushy", freezing range with resulting hot-shortness it is difficult to prevent "draws" or checks at corners or where section changes occur due to contraction of the casting upon cooling from the pouring temperature in the sand mold, and surface checks not only reduce sectional strength but also seem to enhance high temperature corrosion at such points. Expert welding may be employed in some cases but it is usually best to scrap such castings.

Only after giving full weight to the various factors which determine working strengths of alloys at high temperatures under usual industrial conditions can the designer safely choose a stress figure adaptable to his particular construction. Most of his structural members will be required to carry loads as transverse beams, sometimes with complicated stress distribution, and values so selected should fall somewhere in the range between the $\frac{M}{S}$ values and the creep values shown on Fig. 7. Except under very adverse operating conditions the recommended $\frac{M}{S}$ values will embody a sufficient factor of safety for the normal run of furnace construction. Only under ideal laboratory conditions, however, can the indicated creep values be employed.

In view of the fact that creep values are up to ten times greater than stresses found to be commercially allowable in usual beam constructions it is evident that proper use of this considerable leeway will call for judgment tempered by considerable experience.

No means better than the $F = \frac{M}{S}$ formula for calculating cross-sections of beam members has been evolved to date and this method employed with properly selected values (particularly figures which have been checked by actual beam behavior) is used in all our designs at the present time.

For ready reference formulae for several commonly employed section shapes are given below.

The values shown on curves of Fig. 6 and Table 5 may be used for extreme fibre stress values in the formula $F = \frac{M}{S}$, wherein

F = Extreme Fibre Stress.
M = Maximum Bending Moment.
S = Section Modulus.

By means of this equation the section of any beam to carry any given load over any span may be determined for any specified operating temperature.

For convenience in calculating sections of cast heat-resisting alloy load-carrying structures, the values of M and S are given herewith for the types of loading and shapes of structural members most commonly encountered in practice.

W = Total load in pounds uniformly distributed
W_1 = Live load in pounds uniformly distributed
W_2 = Beam weight in pounds
P = Live load in pounds concentrated
L = Span in inches

1. With beam supported at both ends:

(a) Load uniformly distributed:

$$M = \frac{WL}{8} = \frac{(W_1 + W_2)\,L}{8}$$

(b) Load P, in middle:

$$M = \frac{W_2 L}{8} + \frac{PL}{4}$$

2. With beam fixed at one end (Cantilever):

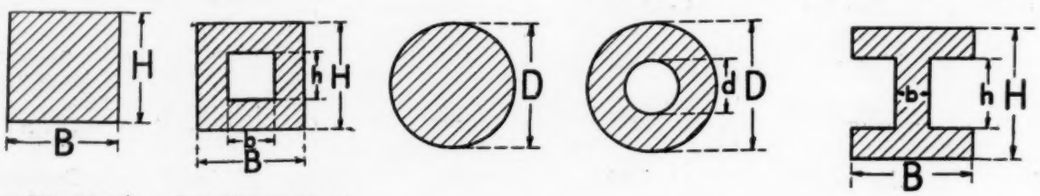
(a) Load uniformly distributed:

$$M = \frac{WL}{2} = \frac{W_1 + W_2\,L}{2}$$

(b) Load P, at free end:

$$M = \frac{W_2 L}{2} + PL$$

The section modulus S, of course, varies with the shape of the section employed. The following standard shapes with corresponding values for S will meet the more common design requirements:



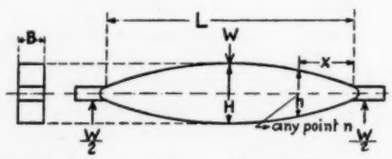
For solid rectangle $S = \frac{BH^2}{6}$

For hollow rectangle $S = \frac{BH^3 - bh^3}{6H}$

For solid cylinder $S = 0.0982 \times D^3$

For hollow cylinder $S = \frac{0.0982 \times D^4 - d^4}{D}$

For I beam $S = \frac{BH^3 - (B - b)h^3}{6H}$



BEAMS OF UNIFORM STRENGTH

In structural members supported at both ends with either uniform or middle load—the extreme fibre stress, F, is greatest at the middle and decreases to zero at points of support. In cantilever type beams the stress decreases from a maximum at the supporting end to zero at the outer end.

Wherever possible, therefore, heat-resisting alloy castings for load-carrying members should be designed of uniform strength instead of uniform section, in order to save the weight and cost of unnecessary alloy. This can be accomplished by tapering either the width or height, and, as the load-carrying ability of a beam varies only directly with the width but directly with the square of the height or depth, the latter method is the most effective.

Assuming a simple rectangular shape, as shown above, of uniform width B, span L, and greatest height of beam H (calculated for point of maximum stress).

Then: h, any intermediate height of beam for any point n, at distance x, from point of zero stress can be derived as follows:

For simple beam, center load:

$$\frac{h^2}{x} = \frac{H^2}{\frac{L}{2}} \text{ or } h^2 = \frac{H^2\,(2x)}{L}$$

It is evident from this equation that the contour of each half span beam is a true parabola.

For simple beam, uniform load:

$$\frac{h^2}{4} = \frac{H^2\,(L_x - x^2)}{L^2} \text{ or } h^2 = \frac{4H^2\,(L_x - x^2)}{L^2}$$

This relationship between h and x, is the equation for all ellipse with vertex at zero.

Uniform strength cantilever beams for end loads and uniform loads, respectively, may be derived in a like manner also from the above equations. In all these beam calculations the difference between elastic and plastic materials must be given full consideration.

The following values may be used to calculate weights of Fahralloy structural members:

Grade	Wt. per cu. in.
F-1	.2845
F-10	.2785
F-3	.2750
F-5	.2945

In addition to alloy members of the plain hanger type straight tension is encountered in furnace members of the catenary class. Chain or flexible apron-conveyors unsupported by skids and hung freely over sprockets or pulleys exemplifies tension members of this kind.

Most of the information concerning a catenary strand can be determined from the formula:

$$h = \frac{WS^2}{8t}$$

Wherein s = Span in feet
h = Deflection at center
t = Tension at center
T = Tension at any point
= t ÷ Cos Φ = Selected Safe Stress
W = Wt. per ft. in pounds.

STABILITY

Any alloy considered for industrial high-temperature service must be examined carefully with respect to phase equilibrium or allotropic changes or varying component solubility under heat, or upon heating or cooling.

Alloys having marked critical points or with constituents easily dissolved at high temperatures and precipitated at lower temperatures or in which structural changes occur with temperature fluctuations are not suited to cycle operation—although, in certain cases, satisfactory for use under constant temperatures.

This is a relative matter as no alloy in the commercial heat-resisting class possesses a chemical equilibrium perfectly stable against all temperature changes.

This feature has not received full recognition in the conduct of creep tests, nor in the interpretation of creep data.

Creep values for a given alloy secured under laboratory conditions of constant temperature and continuous stress do not necessarily measure the ability of the same alloy to carry a load in operations involving time-temperature cycles. For example, an alloy showing a plastic stretch of one per cent per 10,000 hours in a laboratory test might give a far greater rate of elongation if the test duration were made up of hundred hour or ten hour or one hour cycles—particularly if under full load during heating and cooling as in normal industrial operations.

A certain alloy may age harden and become brittle if held at a temperature of 1250-1400 degrees Fahrenheit whereas the alloy again becomes soft and tough if heated to 1900 degrees Fahrenheit. This indicates internal changes, such as precipitation and re-solution over the range up to 1900 degrees Fahrenheit with accompanying strength loss, dimensional changes, and the like.

The straight chromium-iron-carbon alloys are the most subject to age hardening while the high nickel alloys (Fahralloy F-5 and F-1) are most free.

The Fahralloy grades range in order of descending stability about as follows: F-5—F-1—F-10—F-2—F-3—F-8.

F-8 (1808) and nearby grades are particularly bad offenders in this respect but possess satisfactory strength up to 1750 degrees Fahrenheit and can be employed for intermediate and quite constant temperatures.

F-1—F-5—F-10 grades can be considered commercially stable under practically all operating conditions regardless of time or temperature cycles.

The ideal alloy in this respect would be a perfectly homogeneous solid solution at all temperatures but none such is available in this field.

Perfectly stable heterogeneous equilibrium would be just as satisfactory but even in the best alloys available in this field there is some shifting of equilbria with changing temperatures.

Figure 9 contains the same alloys as Figure 4 but in this case physical properties, including brinell hardness, for these alloys are listed in the as-cast state together with the brinell value for each after the indicated aging at 1250-1600 and 2000 degrees Fahrenheit, respectively.

The hardness and magnetic changes indicated should not be taken too seriously nor considered as quantitative behavior under long time service but they are nevertheless an indication of the trend of these alloys when arranged in an order of relative stability.

Test bars marked "broke" indicate such a brittle condition that the piece fractured under the brinell ball.

THERMAL EXPANSION AND CONTRACTION

Stresses set up by temperature fluctuations cause more failures in the general run of high temperature mechanisms than all other causes combined.

If metallic equipment could be operated and maintained at some specific high temperature without being subjected to greater temperature fluctuation than under atmospheric conditions, the problems in design of heat-resisting mechanisms, would be more difficult than in ordinary engineering practice under normal conditions which involve only surface stability and strength of materials.

The extreme importance of this factor in design or operation is better appreciated when it is considered that the temperature fluctuations of only a few degrees under atmospheric conditions cause buckling or cracking of massive concrete structures such as pavements or bridges and dangerous stresses in all steel structures unless suitable provision has been made for expansion and contraction. In high temperature engineering, allowance must be made for dimensional variations which are many times as great as those encountered in ordinary structural engineering.

Warping or buckling and cracking of an alloy structural member is certain to result if it is repeatedly subjected to intense seriously uneven heat-

SYMBOLS AFTER BRINELL NUMBERS SHOW THE MAGNETIC PROPERTIES. M = MAGNETIC; SM = SLIGHT. MAG.; NM = NON MAG.

			ANALYSIS						PHYSICAL PROPERTIES AS CAST					BRINELL AFTER AGE HARDENING		
		HEAT NUMBER	C	Mn	Si	Cr	Ni		YIELD POINT	TENSILE STRENGTH	ELONG 2" %	RED. %	BRINELL	120 HRS. 1250° F	30 HRS. 1600° F	30 HRS. 2000° F
1		1422	.43	.93	.24	18.06	37.47		43680	69980	13.0	14.0	156 NM	217 M	183 M	183 M
2		1357	.65	.25	.35	18.92	35.76	SAME HEAT					170 NM	269 M	212 M	159 M
3	Si	1357-A			1.47			SAME HEAT					179 NM	170 NM	187 NM	170 SM
4		1357-B			2.91			SAME HEAT					187 NM		187 NM	179 NM
5		1423	.83	.12	.47	17.63	36.80		40920	64170	4.0	6.2	207 SM	207 M	241 M	187 M
6		1437	.35	.77	1.48	23.33	12.73						196 NM	217 NM	170 NM	163 NM
7	W	1437-A	.40	.77	1.27	23.41	11.65	W 4.76					207 NM	228 NM	267 NM	196 NM
8		1443	.33	1.44	1.07	25.36	9.34	W 2.94	41740	76890	21.5	11.8	183 NM		217 NM	183 NM
9		1469	.38	1.54	.88	22.75	6.00		58020	100460	26.5	27.3	187 M	202 NM	196 NM	
10		1449	.32	1.27	.22	28.38			52250	52250	NONE	NONE	207 M	269 M	228 M	196 NM
11		1341	.45	.27	.30	31.56	0.00						BROKE-M	BROKE-M	262 M	BROKE-M
12	Ni	1341-A					2.90	SAME HEAT					286 SM	321 M	340 SM	BROKE-M
13		1341-B					6.08	SAME HEAT					255 NM	269 NM	340 NM	255 NM
14		1341-C					10.16	SAME HEAT					241 NM	302 NM	321 NM	255 NM
15		1343	.63	.28	.33	25.09							228 M	BROKE-M	235 M	BROKE-M
16	Si	1343-A			1.60			SAME HEAT					255 M	212 M	255 M	BROKE-M
17		1343-B			3.10			SAME HEAT					286 M	BROKE-M	286 M	BROKE-M
18		1344	.75	.37	.52	28.30							228 M	BROKE-M	228 M	228 M
19	Mn	1344-A		1.37				SAME HEAT					269 M	BROKE-M	241 M	228 M
20		1344-B		3.16				SAME HEAT					321 M	BROKE-M	387 M	418 M
21		1451	2.15	1.15	.82	37.45				65000	NONE	NONE	340 M	430 M		
22		1468	.35	1.07	1.44	10.54	21.09		33870	57380	29.5	38.6	126 NM	149 NM	137 NM	121 SM
23		S-130	.37	.80	2.19	18.05	63.80						149 NM	196 NM	187 NM	153 NM
24		1467	.79	1.31	1.34	15.86	62.85		46100	63270	3.0	2.4	150 NM	200 NM	190 NM	160 NM
25		1471	.75	1.25	2.64	14.67	61.95		63160	70410	1.0	2.0	155 NM	200 NM	195 NM	165 NM
26		1356	.79	.26	.42	13.31	58.24	SAME HEAT					196 M	202 M	196 M	159 M
27	Si	1356-A			1.60			SAME HEAT					217 M	174 M	207 M	170 M
28		1356-B			3.20			SAME HEAT					228 SM	207 M	212 M	179 SM
29		1452	.33	1.29	1.04	26.12	15.27		47410	73780	16.0	13.4	149 NM	196 NM	170 NM	156 NM
30		1466	.35	1.26	.61	26.99	15.32	SAME HEAT	43840	72770	14.5	13.4	156 NM	223 NM	196 NM	
31	Ni	1466-A					19.55	SAME HEAT	45200	75800	18.0	17.8	149 NM	179 NM	183 NM	
32		1466-B					23.82	SAME HEAT	42030	74090	16.0	18.5	149 NM	179 NM	179 NM	
33		1453	.54	1.24	.77	26.51	14.93		56070	68100	6.0	7.0	187 NM	228 NM	241 NM	179 NM
34		1447	.12	.44	.18	20.03	9.18		37690	77340	42.5	41.9	143 NM	183 NM	170 SM	121 NM
35		1446	.14	.45	.23	19.74	9.43		38240	75290	36.0	38.8	143 NM	183 NM	179 NM	179 NM
36		1448	.20	.36	.19	19.44	9.37		30550	70660	53.0	45.2	149 SM	166 NM	149 NM	128 SM
37		1445	1.10	.93	.43	22.35	11.30	AL 1.0	55000	72340	1.15	1.4	277 NM	217 NM		
38		S105	.37	.82	.75	20.39	9.80						179 M	196 NM	196 NM	179 NM
39		1454	.50	1.86	.69	22.49			69980	69980	NONE	NONE	228 M		207 M	BROKE-M
40		1450	1.15	1.65	1.02	21.99			89500	89500	NONE	NONE	286 M	BROKE-M	286 M	286 M
41		1455	1.22	1.62	.68	22.49							321 SM	BROKE-M	477 M	BROKE-M
42		1456	1.54	1.25	2.43	22.88			91600	91600	NONE	NONE	364 M	BROKE-M	364 M	BROKE-M
43		1382	.14	.25	.45	29.82	7.82	SAME HEAT					156 NM	207 NM	217 NM	196 NM
44	Car	1382-A	.56					SAME HEAT					187 NM	269 NM	269 NM	212 NM
45		1382-B	.76					SAME HEAT					228 NM	332 NM	321 NM	286 NM
46		1424	.45	1.38	.36	27.85	9.24		47040	81170	13.0	13.0	207 SM	207 NM	267 NM	
47		1367	.47	.27	.75	28.81	7.40	SAME HEAT					202 NM	228 NM	248 NM	207 NM
48	Mn	1367-A		1.37				SAME HEAT					217 NM	302 NM	286 NM	255 NM
49		1367-B		3.29				SAME HEAT					217 NM	286 NM	235 NM	277 NM
50		1341-B	.55	.25	.25	31.56	6.08						255 NM	269 NM	340 NM	255 NM
51		1341-C	.55	.25	.30	28.48	10.16						241 NM	302 NM	321 NM	255 NM
52		1382-A	.56	.25	.45	29.82	7.82						187 NM	269 NM	269 NM	212 NM
53		1382-B	1.92	.98	1.85	33.30	10.67			72400	2.5	1.8	332 NM	387 NM		
54		1379	.85	3.27	.35	29.42	5.89						241 NM	364 NM	321 NM	277 NM
55		1379-A	.85	4.25	.35	29.42	5.89						228 NM	340 NM	321 NM	277 NM
56		1379-B	.83	4.73	.33	27.76	7.11						212 NM	321 NM	321 NM	269 NM
57		1359	.63	.23	.38	29.24	8.13	SAME HEAT					202 NM	262 NM	241 NM	207 NM
58	Si	1359-A			1.75			SAME HEAT					207 NM	248 NM	241 NM	228 SM
59		1359-B			3.14			SAME HEAT					269 SM	311 NM	277 NM	269 SM
60		1425	1.20	1.49	1.05	28.30	8.85		56730	78200	1.0	1.6	262 NM	BROKE-NM		
61		1420	.37	.11	.56	14.24	49.07	Mo 19.35					262 NM	269 NM	311 NM	241 NM
62		1470	.43	1.10	.73	11.62	48.22	Mo 20.10	54560	65480	NONE	NONE	255 NM	311 NM	321 NM	
63		1062	.99		.63	15.03	47.00	Mo 15.36					302 NM	BROKE-NM	387 NM	430 NM

FIG. 9.

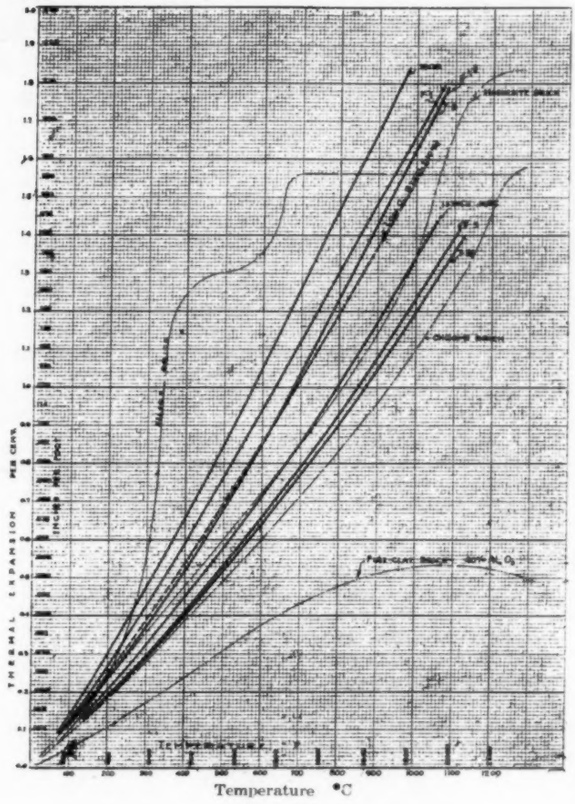


FIG. 10.

ing and cooling because of localized flow due to thermal expansion and contraction strains. In rigidly restrained members, wherein plastic flow is alternately compressing and stretching due to thermal expansion and contraction, cracks are certain to form through fatigue after many reversals.

Warping, buckling and bulging due to cumulative thermal contraction or expansion strains are often confused with sagging or other form changes resulting from an actual lack of physical strength at high temperatures, and such failures are often ascribed to structural weakness, whereas the real fault lies in improper design or operation.

Contraction or expansion strains may also occur with changing temperature if one metal or alloy unit is welded or otherwise rigidly joined in an operating assembly with another material having different thermal expansion rates. Temperature gradients also set up stresses so that localized hot-spots should be avoided whether due to uneven application of heat or to the unequal heating or cooling rate of adjacent thick and thin sections.

The **rate** of expansion for all materials changes with the temperature and is usually greater at higher temperatures. This change in rate of expansion or "temperature coefficient" of thermal expansion is not the same for a given material throughout all temperature intervals, so it is quite evident that expansion allowances, based on the room temperature rates ordinarily given in tests or in trade literature, will be too low and structures designed from such data will fail through compression thrusts.

Thermal expansion values for several grades of Fahralloy, together with curves for steel and several common grades of refractories for comparison, are shown in Figure 10.

There is one other form of dimensional change which complicates stresses where fluctuating temperatures are present and this factor must not be overlooked in the selection of suitable analysis. Critical points due to allotropic changes occur in certain grades and these are accompanied by rather abrupt changes in rate of expansion, and any temperature gradient which includes this critical temperature point will set up stresses of considerable magnitude.

In properly balanced "heat-resisting" alloys such effects are not serious. The low alloy content grades are bad offenders in this respect. This is particularly true of the "1808" type, the chromium-iron grades and chromium-nickel-iron alloys in which the nickel and chromium total less than 30%.

SPECIFIC HEAT AND HEAT CONTENT OF HEAT RESISTING ALLOYS

In many high-temperature chemical and metallurgical processes, containers or conveying units are alternately heated and cooled through temperature intervals sometimes as great as 2000 degrees Fahrenheit. In such cases it is often desirable or necessary

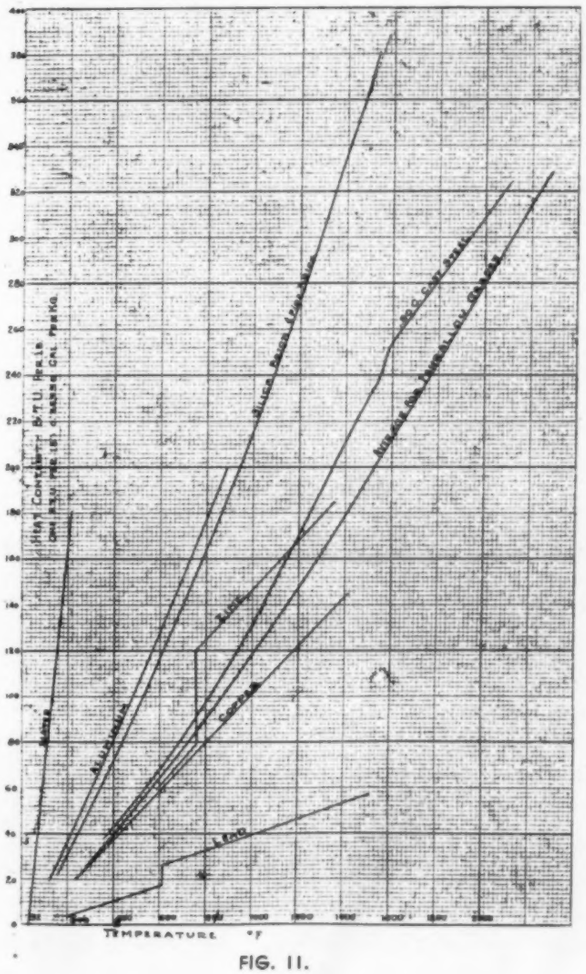


FIG. 11.

to know the specific heat or heat-absorbing capacity of these operating units, so that heat loss per cycle may be calculated.

The specific heat of metals and alloys varies with the temperature, and usually increases as the melting point is approached. This rate of increase, or temperature coefficient, is not necessarily the same at all temperatures, but for practical purposes these temperature variations can be shown on a smooth curve. The value of accurate heat-content data is apparent from a casual study of ordinary steel-treating operations, or continuous enameling operations, particularly with electric heating. Many hundreds of tons per day of carburizing and annealing containers and continuous mechanisms of various types are heated to around 1800 degrees Fahrenheit and allowed to cool in the open air with a resulting loss per heat cycle of up to 290 B.T.U. per pound or 580,000 B.T.U. per ton of container metal, and this extra cost in terms of coal or oil or dollars is quite an important item.

The curves of Figure 11 give heat-content values for heat-resisting alloys along with those of several other materials for comparison, and these facilitate the direct reading of heat losses for any given operating temperature cycle.

Other important properties to which specific heat is interrelated in the design of high-temperature mechanisms are—physical strength, thermal-conductivity, and heat-emissivity or absorption factors. Surface conditions due to corrosion also have some effect in determining whether an alloy unit will accumulate or give out its full capacity for heat with each temperature cycle, and this is affected also by the time of each cycle or by the rate of temperature change.

The cross-section of an alloy unit or structural member is usually determined by its unit strength at operating temperatures. It is therefore quite obvious that the stronger the alloy the lower the weight required to carry a given load, with correspondingly lower alloy cost, and lower heat losses per cycle of operation. This is particularly important in processes where the weight of containers or carriers may be great as compared with that of the material treated.

The intrinsic thermal conductivity of a metal or alloy or its heat emissivity or absorption power may influence heat losses insofar as they affect the rate with which metallic unit approaches the temperature of its surroundings on either heating or cooling.

Heat-resisting alloys are commonly used as containers or conduits for the heating of one fluid by another, or involve heat-transfer in some manner, and their characteristics in this respect are quite well known.

The following is a very elementary treatment of a highly specialized subject but it will at least be of help in illustrating some simple every day problems.

Heat-transfer is carried out by one or more of three methods: Conduction, Convection or Radiation.

CONDUCTION AND THERMAL CONDUCTIVITY

The rate of heat flow by conduction is directly proportional to the coefficient of heat-conductivity (K);—to the cross sectional area;—to the temperature difference, and inversely proportional to the length of path, or—

$$\text{B.T.U. per hr.} = \frac{KA\ (T_1 - T_2)}{L}$$

Wherein K = Coef. of heat conductivity
A = Area in Square feet
T_1 = Temperature of Hot Area in degrees Fahrenheit
T_2 = Temperature of Cold Area in degrees Fahrenheit
L = Length of path or thickness of plate in inches.

In calculating conductivity through pipe of relatively small diameter and with thick walls the logarithmic mean sectional area should be employed. This is determined as follows:

$$\text{Mean area } A = \frac{A_2 - A_1}{2.3 \log \left(\frac{A_2}{A_1}\right)}$$

Wherein A_2 = outer area
A_1 = inner area

The intrinsic thermal conductivity of the alloy itself, however, is usually of relatively small importance in its bearing upon overall transfer of heat because any thin wall of alloy will usually conduct heat from one surface through the section to the other surface at a greater rate than it can be received or delivered by radiation or convection. The relatively low specific conductance of all heat-resisting alloys must be considered however, in any attempt to secure temperature equalization throughout a given unit and in cases where thermal expansion stresses may otherwise be set up and do damage, steep temperature gradients can be avoided by providing a large section to give greater heat equalization by conductance. This low conductivity, however, is of great service in the construction of assemblies where alloy units, for instance, must project through a furnace wall, and renders it possible to maintain temperature gradients up to 200 degrees Fahrenheit per inch.

In any case high thermal resistance along with a parallel high electrical resistance as compared to pure metals is a fundamental property of these alloys and the very alloying elements which impart resistance to oxidation and physical strength likewise increase thermal and electrical resistivity, so that low thermal

conductivity in heat-resisting alloys must therefore be accepted as unavoidable.

Normal temperature average values for thermal conductivity (rate of heat flow commonly designated K or k in B.T.U. per square foot, per inch, per hour, per 1 degree Fahrenheit) for some common materials and various grades of Fahralloy are as follows:

Material	Normal Temperature Therm. Cond. "K"
Silver	2900
Copper	2600
Aluminum	1400
Graphite	1000
Steel (low carbon)	420
Nickel	400
Lead	230
Cast Iron	200
Fahralloy 1400	180
1700	160
2800	150
F-3 — 2802	110
F-8 — 1808	104
F-10 — 2812	100
F-1 — 1835	100
F-5 — 1865	100
2080	100
Carborundum	20.
Fire Brick	6.
Water	5.
Sil-O-Cel	.5
Air and Most Gases	.15

(For corresponding c.g.s. units multiply the above figures by 0.0003445.)

The thermal conductivity of most non-metallic refractories **increases** with rise in temperature. In the case of silica brick and fire brick, the conductivities at 2000 degrees Fahrenheit are practically double the room temperature values. For most metals and low content alloys of iron, on the other hand, thermal conductivity **decreases** with rising temperature, but for most of the high chromium and nickel-chromium alloys the conductivity increases* 25%-50% up to 1250 degrees Fahrenheit with further increases or sharp decreases depending upon phase or allotropic changes encountered at higher temperatures. The temperature coefficients for refractory alloys are fairly low, however, so that thermal conductivity figures for lower temperatures may be employed, over wide ranges, with a factor of safety if desired.

In many types of heat-transfer equipment the factor of thermal conductivity of the metal section itself can be ignored, practically, because the resistance to passage of heat presented by the two surfaces of the intervening wall is so much greater.

This is particularly true in gas—metal—gas heat-transfer, as exemplified in convection type air preheaters which may show overall rates of from 0.5 to 10. B.T.U./sq. ft./hr./°F. whereas the conductive capacity of the metal wall itself will vary from 100 up to 400 B.T.U./hr./inch/°F.

In condensation equipment, or liquid—metal—liquid types, (particularly molten metal containers) the factor of conductivity becomes increasingly important but in nearly all cases surface resistance factors are of greater moment.

* Shelton & Swanger—Trans. A.S.S.T. December, 1933.

Convection

The rate of heating by convection is determined by temperature differences and the velocity and freedom of circulation of the heating or treated fluid, and these variables are determined by design or operation, so that the part played by convection in the overall rate of heat-transfer is entirely a function of the design of high temperature alloy equipment, and is not influenced by any known intrinsic property of the alloy itself.

Contact Resistance or Skin Effect

When a fluid (liquid or gas) is in motion over the surface of a solid, a more or less stationary film or skin of the fluid adheres to the solid and the thickness of this is dependent upon the character of the fluid and upon the velocity of its flow. Most fluids, and gases particularly, are very poor conductors of heat, so that the rate of flow of heat from fluid to fluid through a metallic wall is determined more by thermal resistance of surface films than by the conductivity of the alloy itself.

Heat transfer by convection, as in recuperators or the like, is higher with greater fluid velocities which reduce surface resistance by thinning down the surface film. Depending upon the surface scrubbing effect of velocity, overall heat-transfer K. due to convection between two gases and an intervening thin alloy wall will vary roughly from 0.5 to 10 B.T.U., but any rate over 5. will usually call for mechanically induced high velocities.

In the case of air flowing through circular alloy pipes, as in metallic preheater tubes, the transfer **rate** h_i between air and inner wall in B.T.U. per square foot, per hour, per °F. temperature difference can be determined by the formula:

$$h(_i) = \frac{0.88 \times (V)^{0.8} \times (T)^{0.5} \times (S)^{0.2} \times (C_p)}{M^{0.3}}$$

Where

V = Velocity in pounds of gas per square foot of free area—per second.

M = Average Molecular weight of gas.

C_p = Average Specific Heat at Constant Pressure.

T = Arithmetical Mean gas temperature (°F. Absolute).

S = $\dfrac{4}{\text{Inside diameter of pipe in feet.}}$

Overall transfer (H_1) between the air and the inside of pipe = $h(_i)$ times the average (logarithmic mean) temperature difference =

$$h_i x \left[\frac{T_1 - T_2}{2.3 \log \left(\frac{T_1}{T_2} \right)} \right]$$

Where

T_1 = Difference between air and metal at one end of conduit.

T_2 = Difference between air and metal at other end of conduit.

Continuing the example of tubular heater—the conductivity of the tube wall is so high in comparison with heat flow through both surface films that it can be disregarded practically. The **rate** of heat flow $h(_o)$ between the outside of tube and the surrounding furnace gas in cross flow arrangement may be given as:

$$h(_o) = \frac{23\ W}{(W + 1.50\ )}$$

Where

W = Lb. per second per sq. ft. of conduit area at point of highest velocity.

Quantitative transfer equals $H(_o) =$

$h(_o)$ x Logarithmic mean temperature =

$$h(_o) \times \left[\frac{T_1 - T_2}{2.3 \log. \left(\frac{T_1}{T_2}\right)}\right]$$

Radiation

To a far greater degree, quantitatively, than is appreciated even by the experienced designer and operator of high-temperature alloy equipment, the transfer of heat in most heating operations is effected by means of radiation. The role of radiation is very important in processes where a wall of alloy is interposed between the source of heat and the material to be treated, so all properties of alloys which either accelerate or retard heat transfer by this method must be recognized and included in a consideration of design. This is particularly true in the case of muffles, recuperator surfaces, underfired hearths, and retorts or containers where heat may be absorbed by the hot-side surface or given up to the charge from the opposite surface almost entirely by radiation.

A body above absolute zero radiates energy in an amount determined by the temperature and by the character of its surface. Radiant energy impinging upon a body will be partly transmitted, partly reflected and partly absorbed. Metals are not transparent in mass to ordinary heat rays so direct transmission need not be considered in connection with their use at high temperatures.

A considerable proportion of the heat waves striking a metallic surface are reflected and the percentage of the whole so turned off is defined as the "reflectivity factor". Polished metallic surfaces reflect most of the impinging radiant heat while such materials as carbon black or certain metal oxides reflect only a small proportion of it. Polished silver reflects over 95 percent and polished iron about 75 percent, while oxidized iron reflects only about 30 percent.

A body which absorbs all incident radiant energy is defined as a "black" body. Few materials encountered in ordinary industrial high-temperature processes approach ideal black body performance and the proportion of the incident radiation which each substance does absorb is defined as its "absorption factor". Powers of absorption and emissivity for any given material are equal, so absorption values may be termed emissivity factors. These factors for some common materials at service temperatures for alloys average about as follows:

Ideal black body	1.00
Furnace brick	.70—.90
Copper, oxidized	.70
Iron, oxidized	.60—.90
Silver, polished	.03
Heat-Resisting Alloys, bright	.25
Heat-Resisting Alloys, oxidized	.75—.90

It is outside the scope of this paper to consider in detail all factors relating to heat transfer from or to an alloy surface by radiation but for convenience general laws may be stated and simple cases cited to illustrate the manner of utilizing available data in the design of alloy heat-transfer installations.

The law of Stefan and Bolzman is stated in the general equation for total radiation from any body,—

$$H = 0.162 \times A \times \left(\frac{T}{100}\right)^4 \times P$$

In which H = B.T.U. per hour.
A = Area in Sq. ft.
T = Absolute Temperature
P = Emissivity Factor

For net radiation this general equation must be applied to both hot and cold bodies. In the case of two parallel planes of sufficient extent to eliminate error from edge factors, or for two concentric cylinders or spheres of nearly equal diameters the equation becomes:

$$H = \frac{0.162 \times A \times \left(\frac{T_1}{100}\right)^4 - \left(\frac{T_2}{100}\right)^4}{\frac{1}{P_1} + \frac{1}{P_2} - 1}$$

Wherein:—
H = B.T.U. per hour.
A = Area in sq. ft.
T_1 = Temp. (Absolute) of Hot Body
T_2 = Temp. (Absolute) of Cold Body
P_1 = Emissivity Factor Hot Body
P_2 = Emissivity Factor Cold Body

In the case of a small body entirely surrounded by a large body, as for example a small water-cooled pipe in a hot furnace chamber—the equation becomes:—

$$H = 0.162 \times (A) \times (P) \times \left(\frac{T_1}{100}\right)^4 \left(\frac{T_2}{100}\right)^4$$

Wherein:—
A = Area of small body
P = Emissivity of small body

These two cases exemplify common relationships encountered in the use of alloys at high temperatures and for more complicated assemblies reference should be made to treatises on the subject of radiation.

It should be noted that in alloys the emissivity or absorption factor is dependent only upon the character of the exposed oxide surface and not upon its thickness, so that the amount of heat which can reach the mass of metal beneath the oxide coating

or pass through it will be decreased to a serious degree by the thermal resistivity of a **thick** oxide coating, as the thermal conductivity of the alloy itself is nearly one hundred times as great as that of the ordinary oxide scale.

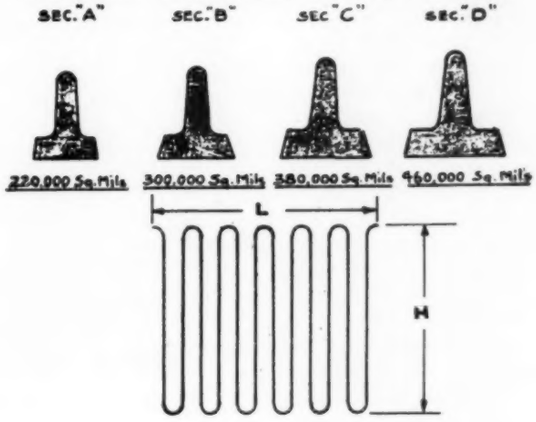
When heat-resisting alloy castings are exposed to safe high temperatures, the surface oxide formed is adherent and very thin. This film serves to increase the surface absorption power without at the same time counteracting this advantage by introducing additional thermal resistance as does the heavier oxide coating or scale such as forms on steel.

Electrical Properties

For large-scale, rugged, foolproof, electrically heated installations, the use of cast resistors has found considerable application in the field of heavy service formerly held by wire or ribbon type resistors. Due to the fact that castings for this purpose are not handicapped by rolling or drawing limitations as to composition it is possible to provide cast resistors having superior strength and resistance to oxidation. Furthermore, resistors of this type can be made of alloys immune to sulphur gases and certain other active gases or chemicals.

Cast resistors are more rigid, and occupy small space as they are mounted practically against the wall. Hangers are of alloy and easily mounted in either new or old furnaces. In very small furnaces, however, wire or ribbon are usually preferable be-

STANDARD FAHRALLOY FURNACE GRIDS.



Grid No.	Sect'n	L	H	Resistance of Grid at Fahr, temperature noted					M	K	Wgt.
				400°	800°	1200°	1600°	2000°			
1	"A"	19.5"	22"	.0441	.0465	.0483	.0495	.0509	19'	5.75	21.5 lbs.
2	"A"	19.5"	18"	.0348	.0375	.0382	.0391	.0398	15'	4.50	20 "
3	"A"	19.5"	14"	.0256	.0269	.0280	.0287	.0292	11'	3.25	18 "
4	"B"	21 "	22"	.0324	.0340	.0354	.0364	.0370	19'	8.00	29.5 "
5	"B"	21 "	18"	.0256	.0269	.0280	.0287	.0292	15'	6.50	27 "
6	"B"	21 "	14"	.0188	.0197	.0205	.0211	.0214	11'	5.00	24.5 "
7	"C"	22.5"	22"	.0256	.0269	.0280	.0287	.0292	19'	10.00	38.5 "
8	"C"	22.5"	18"	.0201	.0212	.0221	.0227	.0231	15'	8.00	34.5 "
9	"C"	22.5"	14"	.0148	.0156	.0162	.0166	.0169	11'	6.00	30.5 "
10	"D"	24 "	22"	.0211	.0222	.0231	.0237	.0241	19'	12.00	45 "
11	"D"	24 "	18"	.0167	.0175	.0182	.0187	.0190	15'	9.50	41.5 "
12	"D"	24 "	14"	.0122	.0129	0134	.0137	.0140	11'	7.00	37.5 "

L—Overall length of standard grid section.
H—Overall height of standard grid section.
M—Approximate lineal feet of grid section in resistance.
K—Approximate maximum capacity in kilowatts at 1800° F.

FIG. 12.

cause of the difficulty of providing small cast sections.

Cast resistor elements are mostly of ribbed T or U section and are supplied in sinuous sections having 10 to 15 ft. of element per casting. These are joined by welding to form any length of element required. Cast elements can be used at temperatures above 2000 degrees Fahrenheit.

The resistivity of cast elements at atmospheric temperature varies from about 450 to 500 ohms per square mill foot depending on analysis. Such grids will radiate 2 to 15 K.W. per sq. ft. of grid surface per hour depending upon the temperature of the furnace chamber or that of the charge being heated. This is the equivalent of approximately 3—15 K. W. per hour per square foot of wall surface covered by the grid.

Fig. 12 illustrates the more common sections employed together with data for calculation of design.

Heat Resisting Alloy in the Steel Plant

The writer began furnishing heat resisting castings for high-temperature steel mill service in 1919 and since that time has seen the constantly increasing application of these alloys in this industry and the development of steel mill processes and mechanisms which would not be possible without use of such materials.

The introduction of Fahralloy non-cooled shafts, for roller bottom sheet furnaces in 1926 was the first radical step in getting away from water-cooled sheet furnaces, and this not only cut fuel costs about in half and boosted output but caused considerable improvement in quality and uniformity of product. More than three thousand shafts of this type are in place today. We also have a later design of non-cooled three piece shaft which has been in continuous use since July 1932. This offers advantages in cost and convenience of repair and also, by cutting the free span between bearing, permits lighter castings. A shaft with discs can be used instead of the corrugated roller. If it is desired to avoid the use of bearings on one side, dry shafts can be mounted in cantilever fashion, through one wall of the furnace. The use of hot bearings for dry shafts mounted within the furnace was proposed when this type first came out but have been used only to a minor extent.

In many places for flue regulation, and even in open hearths, water-cooled dampers have been replaced by the multi-piece, non-cooled alloy type and these are typical of the trend from water-cooled steel to non-cooled alloy equipment.

Most of the alloys first used for steel mill service were of the high chromium (25%) low nickel type and later of the 1635 class but the low strength of the former and the lack of resistance to hot gases from high sulphur fuels in the high nickel type caused these to yield to the F-10 (2812) grade. Some users, however, still insist on the 1835 alloy, and in certain applications it cannot be replaced with a lower nickel material.

The F-10 alloy has not quite the high temperature strength of an F-1 analysis, nor its toughness and stability, but it is the best general utility alloy available today. Nickel should not go over 12% nor chromium under 28% when used with coke oven gas or other fuels of high sulphur content, but in natural gas or ordinary oil heating nickel may be increased as desired. When under about .60 carbon this grade machines quite readily and when under .30 carbon it is very easily machined and quite tough and ductile as cast.

Due to "reducing" atmospheres maintained in most normalizing furnaces the alloys used therein will slowly become carburized. A careful analysis of one large dry-shaft installation disclosed a carbon increase in the alloy from about .35 as cast to as high as 1.96% in the hottest portion of the furnace.

Regardless of grade of alloy employed in this type of equipment the most important requirement is soundness and solidity of castings. If there is insufficient feeding or head-metal, internal spongy areas will result and after a period of service these areas will "boil" out or hump up or otherwise show effects of internal oxidation with attending volume increase which is bound to produce serious distortion or disruption. Dry shafts of today will give four or five times the life of the earliest castings which were made according to the then accepted foundry practice.

Steel Plant Applications for Fahralloy

An abbreviated list of the more important standardized steel mill uses for Heat Resisting Alloys include:

1. Normalizing Sheet Furnaces.
   - **A**—Roller Bottom Type.
     - Non-cooled shafts.
       - a—One Piece Design.
       - b—Spindle-Roller Design.
       - c—Hot Bearing Type.
       - d—Discs for Dry and Wet Shafts.
       - e—Doors.
   - **B**—Walking Beam Type.
     - a—Beams.
     - b—Skids.
     - c—Pedestals.
     - d—Chains.
     - e—Doors.
   - **C**—Chain Type.
     - a—Blades and fingers for slotted hearth design.
     - b—Chain and skids for hot chain type.
2. Tin Mill Furnaces:
   - Pack—
     - Chain
     - Pusher
     - Walking Beam
     - Dry Shafts and Discs
   - Pair—
     - Chain
     - Pushers
     - Skids
     - Beams
3. Dampers.
   - Multi-Piece non-cooled non-buckling for Flue Control:—
   - Either slide or butterfly type for producer gas lines, Soaking Pits, Open Hearths and the like.
4. Skids for Billet Furnaces.
   - Rails and Skid Pipe Covers.
   - Skid Shoes.

5. Recuperator and Preheater Parts.
6. Checker Supporting Grids for Hot Blast Stoves.
7. Muffles for Bright Annealing.
8. Retorts for Gas Treating.
9. Stoker Castings.
10. Mill Guides (Twist-entering).

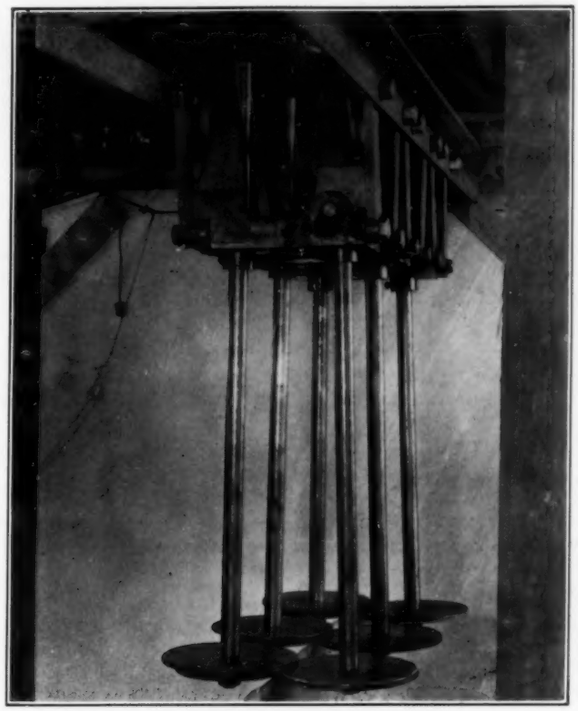


FIG. 13.

11. Hot Shear Blades.
12. Lead Pans.
13. Flue Liners.
14. Billet Scraper Blades.
15. Annealing Boxes.
16. Burner Nozzles (gas fired soaking pits, etc.)
17. Furnace Car Frames.
18. Furnace Car Wheels.
19. Fan Blades and Shafts (Hot gas recirculating or exhaust).
20. Soot Blower Tubes and Hangers.
21. Heating Elements (Resistance).

Many uses such as the above have been proved and fairly well standardized, and others are still on trial while the shortcomings and requirements of present day mill operations and particularly the more drastic sheet requirements of the future will make still further call on heat-resisting alloys. In most cases progress has resulted from an ingenuity of design rather than from any improvement in alloys, and further development will be largely in this same direction. In illustration of this, take the present need for full-finished auto body steel which now requires the use of "rider" sheets in normalizing operations. This procedure increases costs and reduces production.

A logical answer to this requirement would be to heat-treat the sheet without contacting either surface. This has been tried by carrying the sheet through the furnace horizontally with its middle "humped" up by constricting the edges—and by hanging the sheet vertically on hooks or on a crimped edge, but, so far, these methods have not found commercial acceptance. Some of my own development endeavors have been pointed in this direction and test equipment as shown on Figures 13 and 14 was made up to test mechanical possibilities—although not operated at high temperature. In this conveyor the sheet hangs vertically and is driven along in the grip of two pinch rolls mounted on substantially parallel and vertical shafts hanging down through the roof. The shaft bearing frames are pivoted to give a tongs effect and the rollers are pressed together by a spring so that any thin sheet or thick plate can be run without special adjustment. In the test unit many thicknesses from 28 gauge sheet steel to 2" plank were carried perfectly—and very firmly. The grip was sufficient to support the weight of a man on the end of a ⅛" plate as it emerged at discharge.

The roll units were spaced at 12" centers lengthwise by means of suspended roof tile and synchronized rotation of all shafts secured by means of small roller chain and sprockets as indicated.

It was found necessary to cant the axes of the shafts very slightly in the vertical longitudinal plane of the furnace to counteract slippage and to impart a constant slight lift to the sheet upward, edgewise, movement being limited by an overlapping flange on one of the pinch rollers. The total depth of grip required was only ¼" to ⅜", even with fairly crooked edges or cambred sheet. There was some conjecture as to uniformly heating of a narrow vertical chamber but this was not anticipated to give real difficulty. Means were developed for mechanically charging and discharging the sheets and in view of the successful test unit it is my belief that such a furnace will work and turn out a perfect product. Such a construction would show a relatively low first cost and a considerable saving in floor space. Such a job would handle packs—pairs or sheet and plate of varying width and thickness without requiring roller-pressure adjustment. This is given as an example of something impossible to accomplish without the use of heat-resisting alloys.

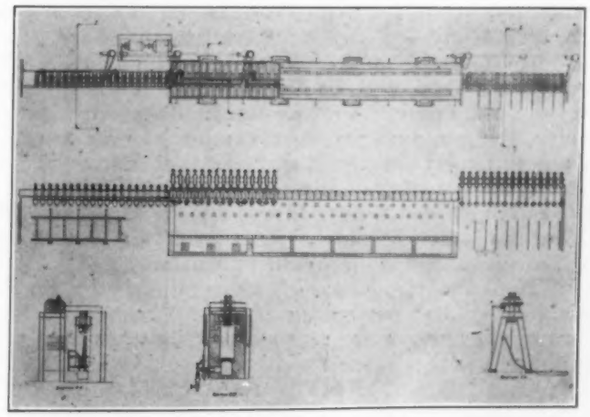


FIG. 14.

Wider use of heat-resisting alloys may also be anticipated in the further development of recuperators for waste heat recovery and pre-heaters for air and other gases. Improvements in ordinary furnace combustion conditions through use of preheaters is becoming widely recognized and the substantial fuel

savings through waste heat recovery is the minor item in many of these cases.

For instance the "enrichment" of lean fuels—such as blast furnace gas—by preheating, is bound to assume considerable importance.

The substitution to an important degree of heat-resisting alloy conduit type of preheater for the commercial checker stoves for open-hearth or blast furnace is becoming a probability due to improvements in both alloys and designs and the writer has completed tests of a 1000 cu. ft. per min. installation which delivers air up to 1350 degrees Fahrenheit at pressures up to 100 lbs. per square inch.

The first cost, maintenance, and general convenience of this type of equipment shows many advantages over the checker-brick type and of course will perform certain operations not possible in the regenerative stove.

As to other future possibilities the steel mill engineer may well give his imagination full play because within the limits of alloy characteristics available there is little in the way of a machine made up of frames, bearings, chain, sprockets—gears, rollers, levers, and the like that cannot be built and operated at temperatures up to 2000 degrees Fahrenheit.

Discussion

Discussion Presented by

Dr. M. A. Hunter, Rensselaer Polytechnic Institute and Director of Research, Driver-Harris Company, Troy, N. Y.
R. S. Brown, Engineer, Calorizing Company, Chicago, Ill.
J. H. Van Campen, Engineer, The Electric Furnace Company, Salem, Ohio.
N. B. Ornitz, President, National Alloy Steel Company, Blawnox, Pa.
Dr. F. A. Fahrenwald, Consulting Engineer, Chicago, Ill.

Dr. M. A. Hunter: I think the first word I would like to say is one of congratulation to Dr. Fahrenwald for the paper he has presented. He has given us so much material that each section of the paper might have been given as a separate paper in itself. I want to compliment him on the completeness of his presentation and am only sorry that sufficient time was not given to make it more detailed.

Now the last word by a long way has not been said on high temperature alloys. We are only now accumulating a vast amount of information about them, but Dr. Fahrenwald has given you the leads which you might very well follow. In the first case he told you that if you want a strong alloy—the strongest alloy—at high temperatures, you are going to get out of the field of iron-chromium alloys. The strongest alloys will be those which contain nickel, and in my opinion the strongest alloy will be the one which contains the least amount of iron possible. Your difficulty in the using of that alloy lies, of course, in the cost of the nickel. And in the future we will have these two things before us—the effectiveness of the high nickel content offset by the cost of the nickel which goes into the alloy.

The second factor which he mentioned is the importance of the chromium content. Alloys of high chromium content are stronger at high temperatures and are usually more resistant to oxidation.

A third factor in the composition of the alloy is the carbon content. The carbides of chromium, soluble only to a limited extent, which can be seen in micrographic section, act as reinforcing beams in the alloy and add greatly to the strength of the alloy at high temperatures.

Additions of silicon are of minor importance. Silicon increases the fluidity of the alloy but renders it less resistant to creep at high temperatures.

The conditions under which the alloy is to be used determine, to a great degree, the composition of the alloy. It is well known that if you are working under high sulphur conditions, a high content of nickel is unsatisfactory. Under these conditions, a high iron content is advisable with the sacrifice of strength at high temperatures.

The picture, then, before you is this. The alloys which are strongest at high temperatures, are the nickel chromium carbon alloys. To meet sulphur conditions, some or all of the nickel can be replaced by iron. The nickel content will directly determine the cost and in an inverse ratio, the resistance to sulphur corrosion. For the most exacting service, where you are going to higher and higher temperatures, you will use higher and higher contents of nickel in your alloys and you will use gases from which the sulphur content has been removed or reduced to a minimum.

N. B. Ornitz: I regret that I didn't hear all of Dr. Fahrenwald's paper and, unfortunately, didn't have a copy that I could have studied before the meeting. The use of high chromium alloys is an economic one. We are always faced with the problem of utilizing such available equipments as are in service. The development of the so-called 28 chrome-10 nickel type alloy is of really recent origin. It is only about ten years ago that the National Alloy Steel Company first introduced this alloy in this country against the opposition of most of the alloy manufacturers who were then sponsoring the so-called 35 nickel-15 chromium alloy. The greater problem at that time was the poor resistance of the high nickel-chromium alloys to the sulphur attack in high sulphur, high temperature atmospheres. This was solved by the so-called 28-10 alloy which I believe is more used today than any other alloy for high heat resistance in fuel fired industrial furnaces.

R. S. Brown: I wish also to congratulate Dr. Fahrenwald for the very complete way he has covered the field of heat-resisting alloys, and it is too bad he did not have longer to go into more detail. I agree with most of what he has said, and if I point out a few places where I must differ, please don't infer that I differ about it all.

One place we do not entirely agree with him is regarding the value of long-time tensile creep tests. It is true as he says that in the plastic deformation of high temperature creep, your elongation or creep is not proportional to the distance from the neutral axis. In a square, round or flat rectangular section that factor will make a good deal of difference in the results. However, most commercial sections that

are used are I-beams or they are hollow rollers in which most of the material—and practically all that which is effective in the section modulus formula is close to the outside surface. In such sections we find in practice that the results obtained from tension tests for creep are readily usuable in the ordinary beam formulae. I should be interested to know on what size sections these transverse tests were made by Dr. Fahrenwald. If they were solid rectangles, where the influence of the center part would be large in figuring the section modulus, then there would be substantial error in using the stresses so arrived at in commercial I-beam sections with little metal near the center.

Since creep proceeds rapidly at first then slows up to a steady rate, any tests based upon measuring the total deformation are bound to give an erroneous impression.

The company with which I am associated has encouraged the University of Michigan Research Laboratories under Dr. C. L. Clark to do a great deal of work in creep testing for us, and one of the conditions that we laid down is that all creep test specimens must be cut from a cast plate and not specially made in cores or an ingot mold. Unfortunately some investigators have not so elected, so that the results are not readily translatable into working stresses on commercial castings.

We also tried to magnify the creep from the ordinary two-inch gauge specimen, and a special furnace was built for work at 1600 to 2100 degrees Farhenheit in accurate measurement of long-time creep. It was found not satisfactory to use the telescope method of measuring the extension of the piece, and it is here measured by the drop-of beam method as you might say. This furnace was specially made with two windings buried in the insulating refractory, one of which takes about two-thirds of the current necessary and the other one-third is run off-and-on through the pyrometer control from a couple on the specimen. Both windings are closer towards the ends than at the center, and the temperature exploration of the furnace will give a maximum variation of 10 degrees at 1800° F.-2000° F. The loading lever has a 10:1 leverage to the point where you measure the drop of the beam and hence we magnify the creep 10:1 before measuring. The specimen is 10 inches long, so this combined with the 10:1 leverage gives a drop of the beam at the gauge point of 100 times the creep of the specimen **per inch.** Measurement is made with vernier micrometer and Ames Depth Dial both instruments showing .0002", thus indicating creep to an accuracy of 1/500,000 inches per inch. It is only with such accuracy that you can be sure the rate of creep is proceeding at a constant rate. The furnace is kept in a room at constant temperature, and the smoothness of the curves and the agreement of duplicate specimens convinces us of its reliable accuracy.

The specimen used was a cross section ½"x1".

We have made up a family of creep curves for an alloy of 26% Chr 19% Ni 1.25% Si, 0.32 C, tested at 1800° F. This is one of the weakest alloys we know and is mentioned here because of some interesting points brought out. It was tested under loads that give reasonable creep results with some of our other alloys. One load of 3000 lbs./sq. in. caused a fracture in 138 hours, and the first thing to be noted is that fracture occured with a total creep or elongation of only 3¼%. Now this material has a total elongation cold in a quick test of around 10%. Yet in rapid creep you only get 3¼%. Your creep failure is entirely around the grains; that is, tearing them apart, and if you go too fast you will get a fracture before you get much total stretch. With the next lighter load the total creep is somewhat greater before fracture. At the lower loads—1700 and 1000 lbs./sq. in., we wish to call your attention to the rapid creep for the first 100 or 200 hours and then a lessened and absolutely steady rate thereafter. Tests of thousands of hours and years of service convince all investigators that once the creep rate has steadied down for 500-1000 hours it will so continue until at least several percent total creep has been reached. This has made it possible to use this type of test of 1000 hours for designing structures for years of service. It also shows the impossibility of so prophesying based on say 100-hour tests.

There has been considerable discussion about the relative value of nickel in chromium iron alloys. I agree with Dr. Fahrenwald that adding nickel in alloys, at least up to 10% greatly increases the creep strength of the metal, but our work shows above that—and I believe he mentioned this—there is a tapering off in strength. Dr. Hunter prophesies that the higher nickels will prove the strongest, and I presume he meant by that above 12%, but we have found the opposite as regards creep strength.

J. H. Van Campen: I would like to ask Dr. Fahrenwald in the mechanical construction or fabrication of alloy parts where producer gas is used with high sulphur content, and where it is a costly problem to eliminate the sulphur, is the minimum nickel and maximum chromium content used for temperatures of say 1900° F. when it is also hard to absorb the creep in such alloys in order to make the construction gas tight?

Dr. F. A. Fahrenwald: Taking gases of combustion from a coal containing 5 or 6% sulphur, which is about the worst condition to be encountered, the highest nickel permissible is around 12%, but along with this the chromium has to be about 27 or 28%.

J. H. Van Campen: Are there any other elements such as Vanadium or Titanium that can be added which would prove beneficial?

Dr. F. A. Fahrenwald: Certain elements such as vanadium have been tried but my own observations have indicated such additions to be uneffective. It has been reported, however, that additions of vanadium, titanium and the like have been beneficial in the case of rolled alloys to decrease inter-crystalline carbide precipitation with its accompanying inter-crystalline corrosion.

J. H. Van Campen: Also, is it possible to use so-called false ageing for these heat-resisting alloys to eliminate excessive creep in operation? In other words, does the creep as hours go on gradually increase indefinitely, or is there a straight line that you might call a saturation point of creep?

Dr. F. A. Fahrenwald: If the alloys were run for considerable periods at operating temperatures some degree of stabilization would result, but due to changes brought about by heating and cooling such preliminary ageing is largely useless.

R. S. Brown: We have not found over a period

of several thousand hours under heat or under changing heat that increasing carbide precipitation, which does take place in any alloy, (and on all of our creep tests we made photomicrographs of the initial and final structure) we do not find the carbide precipitation which takes place in even alloys like 35 nickel and 16 chromium with .40 carbon or in that weakest alloy that I mentioned—26 chromium-19 nickel-.32 carbon, that has increasing carbide precipitation at times—we do not find that that changes the rate of creep one way or the other after a thousand or two hours from what it was originally. We have also taken specimens and put them through cycles of temperatures and tested them for creep and do not find any substantial difference. I therefore think that Dr. Fahrenwald's alarm about a continuous creep testing is not warranted, and we have got several millions of pounds based on such work giving satisfactory service.

One change that takes place in the metal has got to be taken into account. The carbide precipitation does reduce the shock resistance and ductility of the metal. And if there is not a fairly large amount of chromium—I mean by that something like 25 or 28%—you may take enough chromium out of solution so that the grain becomes slightly martensitic instead of austenitic and then you get real brittleness. For that reason we never use relatively low-chromium-high-carbon alloys in places where there is either shock or quick changes of temperature; but, if those things are realized and taken into account relatively high-carbon alloys can be used for certain applications with entire success over a period of years.

Dr. F. A. Fahrenwald: Age hardening is not always due to precipitation of carbides. In carbon-free alloys, for instance, it has been shown that changes from a martensitic condition to austenitic is produced on heating and the reverse of this upon cooling, and I found for instance that very low carbon alloys of the 28-12 type may become very brittle and fragile after a year's service in normalizing or pack heating operations.

I appreciate Dr. Hunter's complimentary remarks, but can go with him only part way in his recommendations for high nickel to impart high strength. We have found that the 18-35 type of alloy is somewhat stronger than the 28-12 or other high chromium low nickel types, but on the other hand we have found that when nickel is increased much above 35% the strength is decreased regardless of the chromium content. There are, of course, other advantageous physical characteristics which accompany high nickel, but unfortunately because of the undue susceptibility to sulphur corrosion full advantage cannot be taken of these desirable properties.

I agree with Mr. Ornitz that probably 90 per cent of the alloy used in steel mill furnaces today is of the 28-10 or 28-12 type. Mr. Brown also seems to agree that the 28-12 is not quite as serviceable as the 18-35 alloy with respect to age hardening or ability to withstand the shocks and bumps in service, but its resistance to sulphur gases practically demands that the high chromium low nickel class be used in the majority of service cases.

N. B. Ornitz: I'd like to add just one point about the carbon content which is a very important one. In the formation of the chromium carbides the chromium is obtained from the chromoferrous ferrite, and therefore the chromium in the ferrite is lower in chromium than it should be. This accounts for many failures of the 22% chromium high carbon alloys in service. This is not generally understood. The first thought is to increase the strength of the alloys by increasing the carbon content, but the increase of resistance to flow or creep, provided the time is long enough, does not come necessarily with increase in carbon content.

Dr. F. A. Fahrenwald: With practically all of these alloys one can count on a carbon pick-up in a reducing atmosphere whether the furnace gases are of the hydro-carbon or carbon-monoxide type. As an illustration of this, a recent careful examination of a Fahralloy dry shaft normalizer at the Weirton Steel Company, in which every shaft was analyzed after about eleven 11) months continuous operation, showed an increase from the original .35 carbon in the castings as they left the foundry to as high as 2.36% in the shafts and discs in the hottest portion of the furnace, so no matter what the carbon content may be at the beginning it is going to end up around several percent anyway.

ITEMS OF INTEREST

PERSONNEL CHANGES

At a recent meeting of the board of directors of the Westinghouse Electric and Manufacturing Company, R. B. Mildon was elected vice president in charge of the operations of marketing, engineering, manufacturing and service, having to do with the products of the South Philadelphia Works. His headquarters will be located at that place.

Mr. Mildon graduated from the Civil Engineering School of Cornell University in 1900 and shortly thereafter was employed by the Union Pacific Railroad and Colorado Fuel & Iron Company in an engineering capacity. In 1906 he was appointed chief engineer of the Duquesne Mining Company and in 1909 became associated with the Westinghouse Company in charge of the Gas Producer Department of the Machine Works at East Pittsburgh. In 1912 he was transferred to the Westinghouse Air Spring Company and re-entered the employ of the Westinghouse Electric and Manufacturing Company in 1916 as assistant to vice president. Recently he has been in charge of the Stoker Department.

G. Walter Sanborn has been elected vice president in charge of purchases and traffic of the United Engineering and Foundry Company, Pittsburgh. He has been purchasing agent since 1921. Mr. Sanborn has long been identified with the steel mill equipment business. In 1902 he was first employed in the machine shop of the William Tod Company, Youngstown, O. In 1909 he became purchasing agent for that company and in 1912 was named field inspector

and expediter for the Wheeling Mold and Foundry Company, Wheeling, W. Va.

Shortly thereafter he returned to the Tod company which, in 1917, was taken over by United Engineering and Foundry Company. At the latter date he was transferred to Pittsburgh as assistant purchasing agent for United and four years later was appointed purchasing agent.

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E. C. Gainsborg, formerly sales manager, Roller Bearing Company of America, Trenton, N. J., has resigned.

▲

George D. Blair, Jr., has been re-elected president of the Blair Strip Steel Company, New Castle, Pa.

C. Allan Ingals, general sales manager since 1929, has been elected vice president to fill the vacancy caused by the resignation of J. C. Blair. Mr. Ingals also was named a director.

E. N. Fulkerson continues as secretary.

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Gunnar Palmgren has been appointed chief engineer of S. K. F. Industries, Inc., Philadelphia. He comes from Sweden where he had been similarly connected with the S. K. F. Industries. He succeeds H. E. Brunner, retired.

▲

Spencer Hazard, formerly vice president, and secretary and treasurer, Florence Pipe Foundry & Machine Co., Florence, N. J., has been appointed president, succeeding the late Walter D. Wood.

Edwin J. Lame has been named vice president in charge of sales and E. Roy Russell, secretary and treasurer. The latter was formerly assistant secretary and treasurer and is succeeded by John J. Troster.

▲

H. J. Saladin, formerly assistant manager of the technical division, Standard Oil Company, Indiana, has been made manager of the technical department, effective May 1. Mr. R. E. Wilkin on the same date was appointed manager of the automotive engineering department and assistant manager of the technical department. These departments will function under the direct supervision of Mr. L. C. Welch, assistant general manager of the lubricating and technical departments.

In his new position Mr. Saladin directs the activities of the technical department, which include the development of new products, the maintaining of specifications on existing products, education work, and the handling of general complaints, particularly those affecting industrial products.

▲

The appointment of H. S. Colby as general sales manager of Combustion Engineering Company has been annouced by R. M. Gates, vice president of that company.

Mr. Colby, until recently, was president of the Air Preheater Corporation. His technical education was acquired at Cooper Union and Columbia University and for the past twenty years he has been engaged in the design, production and sales of steam generating equipment involving boilers, stokers, pulverizers, economizers and air preheaters. This background of experience and an extensive acquaintance in the field of steam generation, eminently fit him for his new duties, which include direct charge of district office activities.

▲

Homestead Valve Manufacturing Company, Coraopolis, Pa., announces the following new exclusive representatives for Homestead valves; Grinnell Company, 240 North Highland avenue, Atlanta, Ga.; L. E. Livingston, 2012 Ward Parkway, Fort Worth, Tex., and the National Supply Company, Toledo, O.

The same company announces for the first time the following Hypressure Jenny vapor spray cleaning machine representatives:

For the Indianapolis district, South Side Body Company, Inc., 109 West Morris street, Indianapolis; for northern Texas, L. E. Livingston, 2012 Ward Parkway, Fort Worth; for Minnesota, North and South Dakota, William H. Ziegler Company, 2331 University avenue, S. E. Minneapolis; for Philadelphia area, Brogan and Company, 810 Race street, Philadelphia; for Pittsburgh and tri-state area, Beckwith Machinery Company, 6550 Hamilton avenue, Pittsburgh; for southeastern Texas, James A. Hall, 110 Byrne street, Houston, and for the state of Wisconsin, Boehck Equipment Company, 2404 West Claybourn street, Milwaukee.

▲

Albert S. Low has been appointed vice president and chief engineer of the Austin Company, Cleveland, engineers and builders, succeeding Harry E.Stitt as chief engineer, the latter to continue as consulting engineer. Mr. Low has been with Austin Company for 21 years, the last 12 in charge of the central district as regional vice president with headquarters in Chicago.

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Charles B. Cushwa is the new president of Commercial Shearing & Stamping Company, Youngstown, O., succeeding the late George F. Alderdice.

▲

At a recent meeting of the Westinghouse Electric International Company, George H. Bucher was elected president of the company.

Mr. Bucher has been connected with the Westinghouse organization since September 1, 1909. After graduating from Pratt's Institute, Brooklyn, New York, in both steam and machine design, and also electrical engineering, Mr. Bucher joined the Westinghouse Electric & Manufacturing Company at East Pittsburgh as a graduate student. In 1911 he was transferred to the Export Department at New York and in 1920 he was appointed assistant to the general manager of the Westinghouse Electrical International Company; and in 1921 he was promoted to the position of assistant general manager and in 1932 to the position of vice president and general manager of the same company.

WITH THE MANUFACTURERS

The Westinghouse Company, realizing the timeliness of proceeding with rehabilitation work while the upturn of business is in evidence and feeling that such procedure will add weight to the general recovery and increase employment, has commenced construction on a new boiler house for plant process and heating purposes at their East Pittsburgh works.

An interesting feature will be the modern, entirely arc welded construction of the new building to house the boiler which will be erected on the site of one of the present boiler plants.

The present plans provide for the erection of a building having five of an ultimate of eleven bays and the installation of one boiler at a total cost of about $400,000. This first installation, which replaces six boilers of the present plant, is one of the four new boilers which will ultimately replace the twenty-four units now in use.

The new boiler, rated at 1600 HP will produce 150,000 pounds of steam an hour and is capable of operation at pressures up to 600 pounds.

Each new boiler installed will have a 450 ton coal bunker and be provided with full automatic coal handling equipment. Equipped with Westinghouse link grate underfeed stokers, Westinghouse ash evacuators, forced and induced draft fans, combustion control and unit stacks, the boilers will provide unusually high efficiencies for the plant.

▲

The Poole Foundry & Machine Company, Baltimore, Md., are distributing a folder describing the Poole, gear type, flexible coupling . This folder may be secured by writing the above company.

▲

"Motor Generator Sets" is the title of the 24-page bulletin 1155 which is being distributed by the Allis Chalmers Manufacturing Co., Milwaukee, Wis. This interesting and well illustrated bulletin may be secured by writing the Allis Chalmers Manufacturing Co.

▲

The Lehigh Valley Railroad has placed an order with The Timken Roller Bearing Company, Canton, O., for roller bearings to be used on all axles, including driving axles, of two class 4-8-4 large high speed steam locomotives.

The Lehigh Valley Railroad has also placed an order with the Timken Company for roller bearings to be used under engine trucks of five locomotives. The locomotives will be built by the Baldwin Locomotive Works, Philadelphia, Pa.

▲

Simplicity of design, control, adjustment to work, and maintenance are the features of the improved General Electric Type WFA automatic arc-welding head now available to industry.

One small motor drives the electrode feed rollers through a simple worm reduction gear and three-speed transmission. At any of the three speeds, selected to suit electrode size, current, and rate of deposition of metal, the electrode is fed at a uniform rate and the arc voltage is accurately maintained. One small rheostat is the only adjusting element necessary. This means quick and accurate control of the electrode feed, as all other operations are fully automatic.

Handwheels swing the nozzle through complete circles in two planes at right angles to each other, thus permitting universal motion of the head. This feature provides the simplest and most accurate means for positioning the electrode with respect to the work or for following an irregular outline as the weld progresses.

The welding head complete consists of an insulated mounting support, an end plate which can be rotated and to which is attached an aluminum-alloy gear case containing the speed-reduction and transmission gears operating entirely submerged in grease. The motor is mounted vertically on the top of the gear case and is of the totally enclosed, ball-bearing type. It has adequate power, not only to feed the electrode but to straighten it as it comes off the reel. A circular aluminum-alloy plate carrying nozzle, wire guide, feed rollers, and feed-roller-pressure-adjusting knob is mounted on the left side of the gear case and can be rotated by means of a handwheel through a worm and worm wheel. A gear-shifting dial on the right side of the case permits ready selection of the desired transmission ratio.

The electric control equipment consists of an enclosed panel on which are mounted standard G-E relays and contactors which maintain in proper sequence the operations necessary in starting, running, and stopping the automatic arc-welding head—and an instrument panel which may be located anywhere but preferably is placed as close to the welding position as possible. This instrument panel carries meters reading arc voltage and current, the arc voltage adjusting rheostat, start-stop buttons, a forward-reverse switch for the electrode feed mechanism, and a selector switch for either manual or automatic operation of a travel carriage if the latter is used.

The standard Type WFA automatic arc-welding head and control is arranged for operation from a 60-volt d-c. supply.

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OBITUARIES

William Ellis Corey, formerly president of the United States Steel Corporation, and later president and chairman of the board of Midvale Steel & Ordnance Co., died at his home in New York on May 11. Mr. Corey was 68 years of age at the time of his death and had been retired for the past five years.

▲

Jonathan Warner, founder of the Trumbull Steel Co., Warren, O., now a part of the Republic Steel Corporation, died in Philadelphia, May 5.

ASSOCIATION NOTES

COMING MEETINGS AND PAPERS

CLEVELAND SECTION

L. A. TERRY, Chairman **W. W. SPANAGEL, Secretary**

Dinner, 6:15 P. M.
Meeting 8:00 P. M.
Cleveland Engineering Society Rooms
May 18, 1934

"Seamless Steel Tubing—Its Manufacture and Use," by W. T. Mahla, Superintendent of Pipe and Skelp Mills, National Tube Company, Lorain, Ohio.

A. I. & S. E. E.

THIRTIETH CONVENTION AND IRON AND STEEL EXPOSITION

September 18, 19, 20, 1934
Cleveland Public Auditorium,
Cleveland, Ohio